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Risk Assessment of Sustainable Pineapple Supply Chain Management

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Abstract

The main objective of this study is to assess risks in the pineapple supply chain and introduce performance indicators for flexibility in Thailand's pineapple supply chain. A risk mitigation strategy was specifically created based on the problems faced by pineapple farmers, from the cultivation process to the distribution process. The questionnaire was meticulously designed to collect data from three sample groups: experts to assess the consequence dimension, and pineapple farmers in Prachuap Khiri Khan province to assess the likelihood dimension, divided into pineapple farmers implemented with and without GAP. The output of this research yielded eleven strategies, including three proactive strategies, three defensive strategies, two remedial strategies, and three reactive strategies. This study not only suggests risk mitigation strategies for sustainable pineapple supply chain management but also presents the outcome of risk mitigation through appropriate strategies that will make pineapple farmers more competitive and sustainable.

Keywords : Sustainable supply chain management; Risk mitigation strategy; Factory pineapple; Competitiveness

Introduction

The canned pineapple processing industry in Thailand serves as a link between agriculture and industry, adding significant value to agricultural raw materials. Prachuap Khiri Khan province leads in Smooth Cayenne pineapple production, cultivation, and harvested areas. Statistical data from 2021 indicated an increase in pineapple planting areas compared to the previous year [1–2]. In 2022, Thailand exported 265,667 tons of canned pineapple, valued at USD 301 million. Furthermore, both the value and volume expanded compared to the previous year. The export report on canned pineapple from the Office of Agricultural Economics, Ministry of Agriculture and Cooperatives, revealed a trend of increasing value and volume based on data from 2019 to 2022 [3]. The price of pineapple increased by 14.61% in 2022 compared to the previous year, as the production volume was insufficient to meet global market demand [4]. This is an important issue for Thailand in creating sustainable added value for Smooth Cayenne pineapple, also known as 'factory pineapple' in the canned pineapple processing industry. In this endeavor, Thailand's canned pineapple processing industry aims to outperform competitors, including the Philippines and Indonesia [5]. These countries emphasize agricultural production by large companies, allowing for continuous production. Consequently, the Philippines and Indonesia can offer lower export prices compared to Thailand due to the efficiency of large-scale farming in controlling production costs. Additionally, factory pineapple production decreased by 14.12% in the second quarter of 2023 [6].

The Ministry of Agriculture and Cooperatives, the Ministry of Industry, the Ministry of Commerce, and related agencies collaborate to enhance pineapple production efficiency in Thailand by supporting large-scale pineapple cultivation through the Pineapple Strategy 2017-2026. The strategic goal is to maintain leadership as the world's number one pineapple exporter by achieving price stabilization, adhering to pineapple product quality standards, and fostering sustainability in the careers of farmers and pineapple processing plants. These outcomes result from implementing four key strategies: 1) production; 2) processing; 3) marketing; and 4) management [7].

The researcher acknowledges the critical role of Thailand's pineapple supply chain, recognizing it as a major agricultural product in Thailand's exports and adding value to the country's agricultural economy. This research focuses on risk assessment in the factory pineapple supply chain in Prachuap Khiri Khan to analyze the environment and potential. Additionally, it aims to formulate strategies to enhance the strengths of the agricultural sector, specifically in the upstream segment of the factory pineapple supply chain. These efforts are geared towards increasing income for the country and driving growth in the agricultural economy.

Methodology

1. Investigating and collecting information in each process

The framework of this study involves the cultivation process to the post-harvest process, consisting of five main stages, i.e., 1) preparation of the field for planting or preparing the soil; 2) preparation of planted shoots; 3) planting, care, and forcing to fruit; 4) harvesting and transportation of pineapples; and 5) sales of goods to processing plants. Farmers face risks at every stage, ranging from minor to severe. The risk of the cultivation process for distribution consists of nineteen risks [8-9] as follows: 1) poor-quality planting plots; 2) errors in forecasting and planting planning; 3) low quality of factors in production; 4) unstable selection of production factors; 5) lack of agricultural tools and equipment; 6) unbalanced efficiency and effectiveness; 7) lack of support for the production process development; 8) poor quality control; 9) severe drought or inadequate agricultural water supply; 10) plant pests; 11) insect pests; 12) ripeness less than 25%; 13) nitrate value more than 25 mg/kg; 14) lack of availability of transport vehicles; 15) unreliable transportation; 16) shortage of labor in the production process; 17) low labor efficiency; 18) uncertain changes in purchase price; and 19) limited product distribution channel.

2. Determination of the risk assessment matrix

The risk assessment is conducted using a risk matrix, which consists of two dimensions, i.e., 1) likelihood, probability, or frequency of facing risks; and 2) consequence, impact, or severity when those risks are faced [10]. The risk assessment matrix in this study utilizes a 3x3 structure (risk assessment matrix 3 by 3), incorporating three levels in each dimension. Additionally, the risk assessment score interpretation for each dimension involves a cross-multiply of all levels in both dimensions [9], as shown in Table 1.

Risk assessment scores 1 and 2 represent slight and acceptable risks, respectively, while scores of 3 and 4 indicate medium and moderate risks. These risks can impact a large population or risk group, leading to disruptions in normal activities and services. The risk mitigation approach involves additional control measures and requires a moderate level of resources. A major risk with a score of 6 is a transmitted risk that has a major impact on small populations or risk groups, causing major disruptions to normal activities and services. The mitigation approach involves implementing a large number of additional control measures and requiring some significant resources. Lastly, an unacceptable risk with a score of 9 has severe impacts on the population or a large number of high-risk groups, causing severe disruption to normal activities and services. The mitigation approach involves implementing several additional control measures and requiring the most significant resources.

Table 1 Risk assessment matrix

<table>
<tr><td colspan="2" rowspan="2"></td><td colspan="3">Consequence</td></tr>
<tr><td>Slightly harmful (1 point)</td><td>Harmful (2 points)</td><td>Extremely harmful (3 points)</td></tr>
<tr><td rowspan="3">Likelihood</td><td>likely (3 points)</td><td>Medium risk (Score 3)</td><td>Major risk (Score 6)</td><td>Unacceptable risk (Score 9)</td></tr>
<tr><td>Unlikely (2 points)</td><td>Acceptable risk (Score 2)</td><td>Moderate risk (Score 4)</td><td>Major risk (Score 6)</td></tr>
<tr><td>Highly unlikely (1 point)</td><td>Slight risk (Score 1)</td><td>Acceptable risk (Score 2)</td><td>Medium risk (Score 3)</td></tr>
</table>

The researcher assesses the risk scores from three sample sizes, categorizing them into three groups based on appropriate numbers. The consequence dimension represents the average score of 10 experts, while the likelihood dimension represents the average score of 118 pineapple farmers. In this study, pineapple farmers were divided into two groups: Group 1 comprises pineapple farmers who implemented GAP (good agricultural practices), totaling 8 persons; and Group 2 consists of pineapple farmers who did not implement GAP, totaling 110 persons. The sample size of pineapple farmers in Group 2 was calculated from the total of 13,670 pineapple farmers in Prachuap Khiri Khan at a 90% confidence level, combined with a 10% tolerance. The risk assessment can indicate critical or unacceptable risks faced by pineapple farmers [11].

3. Determination of the flexibility performance metric

Natanaree Sooksaksun, Kiadtikun Wavnum, Jitraporn Thepklang, and Sasimaporn Seehaworg (2023) discussed the performance metrics of the Supply Chain Operations Reference (SCOR) model, which include reliability, responsiveness, agility, cost, and asset management efficiency [12]. Moreover, Ertugrul Ayyildiz and Alev Taskin Gumus (2021) delved into the SCOR 4.0 model and its performance metrics, encompassing seven aspects: 1) reliability, such as quantity, accuracy, and quality; 2) flexibility, covering production, delivery, and risk; 3) responsiveness, including cycle time and quantity supplied; 4) cost, involving production, transportation, and maintenance; 5) assets, such as working capital, cash-to-cash cycle, and fixed assets; 6) digital technology, encompassing ability, methods, and systems; and 7) information systems, covering integration and content. Additionally, they explained flexibility as the agility to respond to market changes to gain and/or maintain a competitive advantage in a supply chain [13]. This involves addressing errors in inventory management, planning, distribution management, forecasting, etc. [14].

Edgar Ramos, Phillip S. Coles, Melissa Chavez, and Benjamin Hazen (2022) discussed the flexibility metric, which belongs to cluster one in the fuzzy MICMAC analysis. This metric is characterized by not directly influencing the system but being highly unstable, impacting supply chain performance. Although it represents one of the least critical factors, it requires relative attention [14]. The flexibility performance metric in this study is derived from nineteen identified risk issues based on information obtained from the risk assessment [9]. These metrics contribute to the performance evaluation of pineapple supply chain management, enabling pineapple farmers to analyze and assess risks within the supply chain.

4. Environment and potential analysis

The SWOT analysis, or environment and potential analysis, is a tool for analyzing internal and external factors that impact the achievement of an organization's, agency's, or development's goals. Internal factors, or potential factors, involve factors dependent on performance. These factors can be controlled and are often associated with strengths and weaknesses. Examples of internal factors include marketing, input management, personnel, financial factors, etc. An organization, agency, or any development that can perform better than a competitor is considered a strength. However, if an organization has a lower process than competitors, it is considered a weakness that needs improvement.

External factors, or environmental factors, are factors that the organization cannot control or manage. They are often associated with opportunities and obstacles. Examples of external factors include values, labor laws, the economy, etc. These factors may affect the operation in both positive and negative ways. Christine Namugenyi, Shastri L. Nimmagadda, and Torsten Reiners (2019) summarized strengths in the agriculture business that can add value to the agriculture industry, including farming practices, new farming technologies, automation, efficient use of available resources, quality seeds, chemical fertilizers, government subsidies, encouraging organic farming, and sustainable water and energy resources.

Regarding weaknesses that may lead to failure, these include limited access to loans, non-availability of government subsidies, failure to obtain favorable selling rates, poor-quality seeds, interrupted supply of fertilizers and raw materials needed in farming, frequent power outages, and poor-quality farming practices [15].

The SWOT analysis leads to strategy determination. Strength is an operation that drives achievement toward the goal, while weakness is an operation that poses a disadvantage to reaching the goal. Opportunities and threats involve the external environment. An opportunity is an encouraging environment to achieve the goal, while a threat is an environment that could hinder the goal.

5. The development of risk mitigation strategies

The strategy creation, or TOWS matrix, involves the analysis of the relationship between internal and external pair issues, which are SO, ST, WO, and WT. SO is a proactive strategy that takes advantage of internal strengths and external opportunities. ST is a defensive strategy that mitigates external barriers through internal strengths. WO is a remedial strategy that corrects internal weaknesses by considering positive external opportunities. WT is a reactive strategy that reduces the damage caused by internal weaknesses and external obstacles [16].

Critical or unacceptable risks identified through risk assessments are considered weaknesses (Weaknesses: W) if they stem from the actions of the farmers themselves. Environmental factors that create risks in conducting business are regarded as obstacles (Threats: T) if they result from the external environment, which is beyond the control of farmers. If a risk is small or acceptable based on the risk assessment, it is considered a strength (Strength: S) of farmers. Moreover, if it arises from assistance from the external environment, it is seen as an opportunity (Opportunity: O). Furthermore, the researcher plans to develop feasible strategies to establish sustainable pineapple supply chain management to enhance the efficiency of pineapple production in Thailand. This will lead to quality products and can reduce manufacturing costs.

The overall flowchart of this research is shown in Figure 1.

Results and Discussion

1. The pineapple supply chain in Prachuap Khiri Khan, Thailand

The pineapple supply chain is depicted in Figure 2, providing an overview from upstream to downstream. Prachuap Khiri Khan Province serves as the primary cultivation area for Smooth Cayenne pineapples (known as 'factory pineapple') in Thailand, and it is the main location for processing canned pineapples for export. This study focuses on identifying risks upstream in the supply chain, starting from the cultivation process to the post-harvest process for selling fresh pineapples to the canned pineapple processing factory. It serves as the main distribution channel for Prachuap Khiri Khan pineapple farmers, playing a crucial role in Thailand's export of canned pineapples.

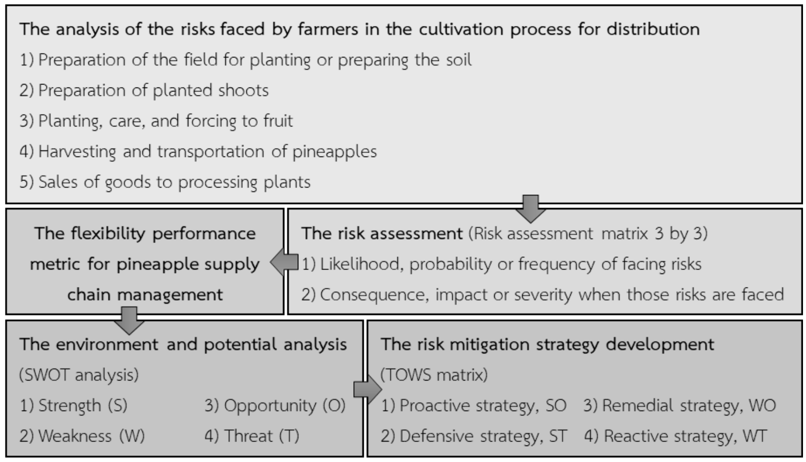

Figure 1 The overall flowchart of this research

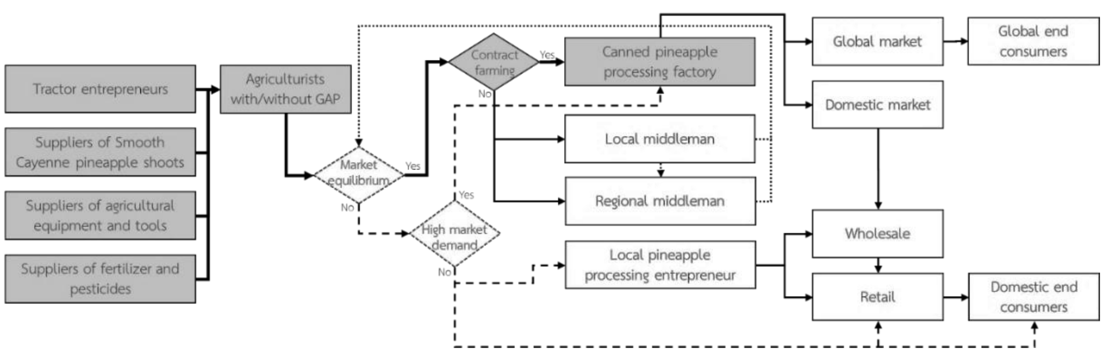

Figure 2 The pineapple supply chain in Prachuap Khiri Khan, Thailand [11]

2. The result of the risk assessment

The risk assessment of nineteen potential risks that may occur to Prachuap Khiri Khan farmers in the pineapple supply chain includes: 1) poor-quality planting plots; 2) errors in forecasting and planting planning; 3) low quality of factors in production; 4) unstable selection of production factors; 5) lack of agricultural tools and equipment; 6) unbalanced efficiency and effectiveness; 7) lack of support for the production process development; 8) poor-quality control; 9) severe drought or inadequate agricultural water supply; 10) plant pests; 11) insect pests; 12) ripeness less than 25%; 13) nitrate value more than 25 mg/kg; 14) lack of availability of transport vehicles; 15) unreliable transportation; 16) shortage of labor in the production process; 17) low labor efficiency; 18) uncertain changes in purchase price; and 19) limited product distribution channel [9, 11].

The study found that risk number 15 is a slight risk, scoring the lowest in the risk assessment. This slight risk includes: 1) farmers not moving their products within two days after harvesting, resulting in fungi on the top and bottom of pineapples; and 2) farmers not properly arranging pineapples on the truck, causing pineapple damage during transportation. Risk numbers 5 (lack of agricultural tools and equipment) and 14 (lack of availability of transport vehicles) are the second-lowest risks and are considered acceptable. Additionally, risk numbers 1, 3-4, 6, 8, 10-13, 17, and 19 with a score of 3 or 4 points are classified as medium or moderate risks. Moreover, the study identifies a total of five major risks, including risks numbers 2, 7, 9, 16, and 18, as shown in Table 2. The results of the risk assessment for the five major risks are consistent across both farmer groups. These major risks can impact yields and may cause significant disruptions to normal activities. Therefore, there is a need for important resources and the implementation of numerous additional control measures to standardize and decrease these risks.

The researcher can elaborate on the five major risks presented in Table 2 by highlighting two interesting observations. Pineapple farmers implemented GAP (good agricultural practices) to effectively mitigate internal risks. Consequently, the risk assessment for risk numbers 2 (errors in forecasting and planting planning), 9 (severe drought or inadequate agricultural water supply), and 16 (shortage of labor in the production process) yielded lower scores compared to pineapple farmers not implementing GAP. In contrast, pineapple farmers who implemented GAP demonstrated increased awareness of external risks. This is evident in the risk assessment for risk numbers 7 (lack of support for the production process development) and 18 (uncertain changes in purchase price), which yielded higher risk scores compared to pineapple farmers not implementing GAP.

Additionally, the researcher can present statistical analyses of three datasets, including 1) a consequence dataset; 2) a likelihood dataset from farmers with GAP; and 3) a likelihood dataset from farmers without GAP. Dataset 1 showed the mean and standard deviation of the risk score for impact or severity when those risks are faced as 2.13 and 0.46, respectively. Datasets 2 and 3 showed the mean and standard deviation of the risk score for the probability or frequency of facing risks as 1.66 and 0.42 for dataset 2, and 1.72 and 0.37 for dataset 3. Moreover, the researcher presented the distribution visualization of three datasets through the normal distribution curve and the error bar, as shown in Figure 3.

Table 2 The result of the risk assessment

Risks	Risk assessment (Evaluation score = Avg. likelihood x Avg. consequence)					Risk assessment		The result interpretation of risk assessment	
	Average likelihood		Average consequence	Evaluation score					
	G1	G2		G1	G2	G1	G2	G1	G2
1) Poor-quality planting plots	1.88	2.18	2.00	3.76	4.36	4	4	Moderate risk	Moderate risk
2) Errors in forecasting and planting planning	1.75	1.95	2.40	4.20	4.68	4	5	Moderate risk	Moderate-Major risk
3) Low quality of factors in production	1.75	1.56	2.00	3.50	3.12	4	3	Moderate risk	Medium risk
4) Unstable selection of production factors	1.50	1.65	1.80	2.70	2.97	3	3	Medium risk	Medium risk
5) Lack of agricultural tools and equipment	1.13	1.17	1.40	1.58	1.64	2	2	Acceptable risk	Acceptable risk
6) Unbalanced efficiency and effectiveness	1.63	1.64	2.20	3.59	3.61	4	4	Moderate risk	Moderate risk
7) Lack of support for the production process development	2.50	2.21	2.60	6.50	5.75	7	6	Major-Unacceptable risk	Major risk
8) Poor-quality control	1.50	1.97	2.00	3.00	3.94	3	4	Medium risk	Moderate risk
9) Severe drought or inadequate agricultural water supply	1.88	2.22	2.60	4.89	5.77	5	6	Moderate -Major risk	Major risk
10) Plant pests	1.50	1.61	2.60	3.90	4.19	4	4	Moderate risk	Moderate risk
11) Insect pests	1.63	1.54	2.20	3.59	3.39	4	3	Moderate risk	Medium risk
12) Ripeness less than 25%	1.25	1.51	1.80	2.25	2.72	2	3	Acceptable risk	Medium risk
13) Nitrate value more than 25 mg/kg	1.13	1.30	2.40	2.71	3.12	3	3	Medium risk	Medium risk
14) Lack of availability of transport vehicles	1.13	1.22	1.40	1.58	1.71	2	2	Acceptable risk	Acceptable risk
15) Unreliable transportation	1.13	1.20	1.20	1.36	1.44	1	1	Slight risk	Slight risk
16) Shortage of labor in the production process	2.00	2.42	2.40	4.80	5.81	5	6	Moderate-Major risk	Major risk
17) Low labor efficiency	1.88	1.55	2.00	3.76	3.10	4	3	Moderate risk	Medium risk
18) Uncertain changes in purchase price	2.63	2.08	3.00	7.89	6.24	8	6	Major-Unacceptable risk	Major risk
19) Limited product distribution channel	1.75	1.74	2.40	4.20	4.18	4	4	Moderate risk	Moderate risk

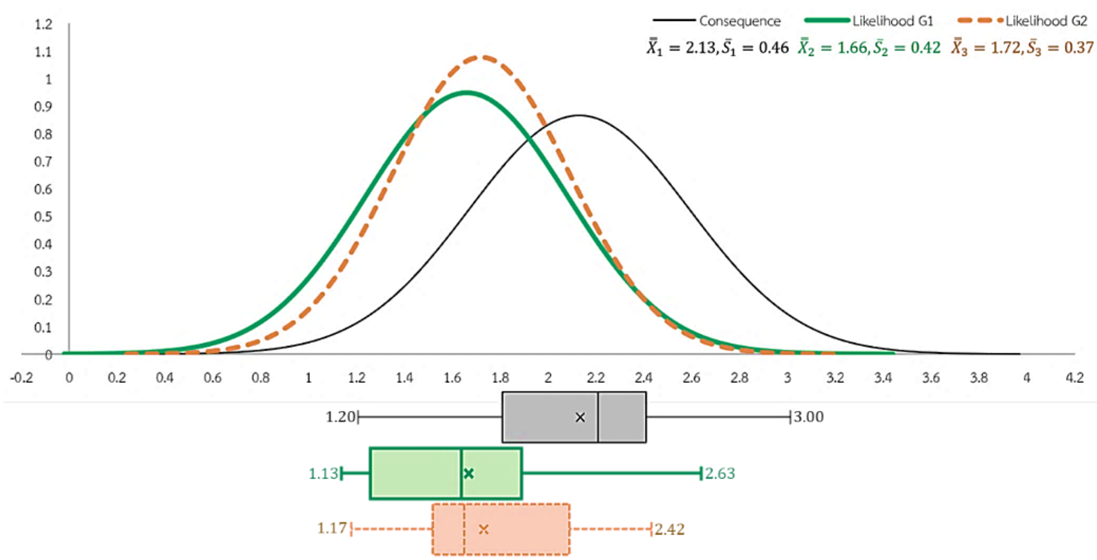

Figure 3 The distribution visualization of three datasets

3. The flexibility performance metric in the pineapple supply chain

The researcher can explain the risk weight derived from the average consequence of each risk as determined by 10 experts in Table 2. The calculated risk weight is shown in Figure 4. Additionally, the average likelihood in Table 2 from pineapple farmers implemented with and without GAP is converted to integer values of 1, as indicated in Table 3. The risk value above was calculated by using the risk weight, which is the weighted risk value for each risk. Subsequently, the flexibility performance of pineapple farmers is determined by subtracting the total risk percentage from 100%. The flexibility performance of pineapple farmers implemented with GAP is 42.42%, and pineapple farmers implemented without GAP is 40.81%, as shown in Table 3.

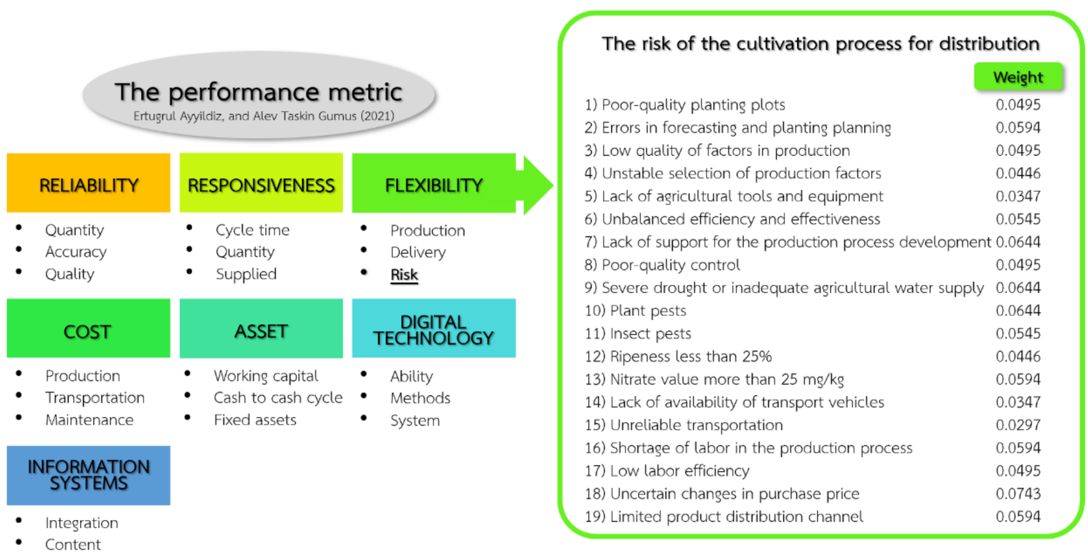

Figure 4 The risk weight for calculating the flexibility performance in each metric

4. The result of the environment and potential analysis

The interpretation of the nineteen risk assessments leads to an environment and potential analysis involving three strengths, two weaknesses, and three threats. Moreover, the researcher studies and gathers opportunities to help and support the Thailand pineapple supply chain from the Agricultural and Cooperative Development Plan of Prachuap Khiri Khan Province (2023-2027) as follows: Opportunity (O) is defined by three issues, i.e., 1) O1: advancements in new technology; 2) O2: government policies supporting agriculture across administrative tiers; and 3) O3: growing global demand for agricultural products [17]. Threat (T) involves three issues, i.e., 1) T1: water resource insufficiency in agricultural land due to a severe drought; 2) T2: labor shortages encountered by farmers in the production process; and 3) T3: price volatility confronted by farmers. Strength (S) consists of three issues, i.e., 1) S1: proficiency and knowledge of farmers in safely transporting and distributing agricultural products; 2) S2:

Table 3 The flexibility performance in each metric of pineapple farmers in Prachuap Khiri Khan, Thailand

Risks	Weight	Risk value		Weighted risk value	
		G1	G2	G1	G2
1) Poor-quality planting plots	0.0495	0.6267	0.7267	0.0310	0.0360
2) Errors in forecasting and planting planning	0.0594	0.5833	0.6500	0.0346	0.0386
3) Low quality of factors in production	0.0495	0.5833	0.5200	0.0289	0.0257
4) Unstable selection of production factors	0.0446	0.5000	0.5500	0.0223	0.0245
5) Lack of agricultural tools and equipment	0.0347	0.3767	0.3900	0.0131	0.0135
6) Unbalanced efficiency and effectiveness	0.0545	0.5433	0.5467	0.0296	0.0298
7) Lack of support for the production process development	0.0644	0.8333	0.7367	0.0537	0.0474
8) Poor-quality control	0.0495	0.5000	0.6567	0.0248	0.0325
9) Severe drought or inadequate agricultural water supply	0.0644	0.6267	0.7400	0.0404	0.0477
10) Plant pests	0.0644	0.5000	0.5367	0.0322	0.0346
11) Insect pests	0.0545	0.5433	0.5133	0.0296	0.0280
12) Ripeness less than 25%	0.0446	0.4167	0.5033	0.0186	0.0224
13) Nitrate value more than 25 mg/kg	0.0594	0.3767	0.4333	0.0224	0.0257
14) Lack of availability of transport vehicles	0.0347	0.3767	0.4067	0.0131	0.0141
15) Unreliable transportation	0.0297	0.3767	0.4000	0.0112	0.0119
16) Shortage of labor in the production process	0.0594	0.6667	0.8067	0.0396	0.0479
17) Low labor efficiency	0.0495	0.6267	0.5167	0.0310	0.0256
18) Uncertain changes in purchase price	0.0743	0.8767	0.6933	0.0651	0.0515
19) Limited product distribution channel	0.0594	0.5833	0.5800	0.0346	0.0345
				0.5758	0.5919
100% performance minus the total risk percentage =				57.58%	59.19%
The flexibility performance of pineapple farmers in Prachuap Khiri Khan, Thailand				**42.42%**	**40.81%**

5. Sustainable development of Thailand's pineapple supply chain

The strategy analysis aims to enhance the performance of Thailand's pineapple production, aiming to produce high-quality products and reduce production costs. The result of this analysis leads to the development of eleven sustainable strategies for preparedness of farmers' vehicles for agricultural product transportation and distribution; and 3) S3: adequate agricultural tools and equipment possessed by farmers for pineapple cultivation. Weakness (W) includes two issues, i.e., 1) W1: lack of support for advancing the production process through the adoption of innovations for enhanced production and reduced costs by farmers; and 2) W2: a deficiency in statistical market data hinders precise forecasting and strategic planning for farmers. Thailand's pineapple supply chain. Three strength issues and three opportunity issues result in three SO (Strength-Opportunity) strategies. The ST strategy is analyzed for defense against the relationship between strengths and threats. Thus, the researcher creates three ST (Strength-Threat) strategies. The WO strategy is analyzed for remediation based on the relationship between opportunities and weaknesses, and the researcher can create two WO (Weaknesses-Opportunity) strategies. Last, the WT strategy is analyzed for reactivity from the relationship between weaknesses and threats, from which the researcher can create three WT (Weaknesses-Threats) strategies, as explained in Table 4. Specific aspects of this study demonstrate congruence with the research conducted by Christine Namugenyi, et al. (2019) and Radasa Netsangsee (2022), such as new farming technologies, automation, efficient use of available resources, quality seeds, chemical fertilizers, government subsidies, encouraging organic farming, sustainable water and energy resources, training on pineapple quality development, marketing channel development, etc. [15, 18].

Table 4 Sustainable strategy development

Strategy		Strategy detail
Three SO proactive strategies	S1O2	The design and development of equipment for loading and unloading aims to enhance the efficient movement of agricultural products within fields. This equipment streamlines the loading and unloading processes of transport vehicles, resulting in reduced time requirements and the elimination of unnecessary procedures. Consequently, it contributes to the reduction of potential damage to agricultural products during transportation.
	S2O1	The queue management system for direct delivery from the farm to the pineapple processing factory can be enhanced through technology. This approach not only provides farmers with real-time information about their position in the queue but also leads to a significant reduction in waiting times.
	S3O3	New technology and innovation (e.g., drones, automatic watering systems, etc.) can save time in the farmer's cultivation process, bring about greater accuracy, and lower production costs compared to human labor. Additionally, it can enhance safety for farmers when using agricultural chemicals.
Three ST defensive strategies	S1T3	The challenge of uncertain purchase prices. A strategy involves promoting and distributing fresh pineapples through various initiatives, such as marketing campaigns and fruit festivals, as well as seeking collaboration to encourage fresh pineapple consumption. This approach offers an initial solution to mitigate the impact of price fluctuations.
Three ST defensive strategies	S2T1	An initial solution to mitigate the effects of agricultural water scarcity caused by drought is to use vehicles for direct transportation from nearby water resources to plantation areas. This approach helps safeguard against adverse effects resulting from insufficient agricultural water for farming.
	S3T2	The challenge of labor shortages requires a strategic approach, such as operating small farms collaboratively to enable collective support in hiring seasonal foreign laborers, facilitated by government programs.
Two WO remedial strategies	W1O2, W1O3	The government must establish a knowledge-sharing center to instruct on new technology and innovation to support the development of the farmers' production process. This will lead to lower production costs while maintaining or improving the quality of pineapples.
	W2O1	Farmers should incorporate additional distribution channels, particularly during periods of oversupply for both fresh and processed pineapple products, within small and medium-sized enterprises (SMEs) by utilizing online platforms. These platforms enable direct connections with consumers, facilitating more efficient distribution.
Three WT reactive strategies	W1T1	The challenge of coping with severe drought and the resultant water shortage on farmland requires farmers to apply modern technology and innovative techniques in their cultivation practices. This approach enables the efficient management of agricultural water resources by tailoring watering schedules to the specific needs of the plants, ensuring cost-effective and sustainable water use.
	W1T2	Farmers should adopt technologies and innovations to replace manual labor (e.g., automation and smart systems) across the entire planting process. This transition aligns with the principles of intelligent agriculture, enhancing efficiency and productivity while mitigating the labor shortage.
	W2T3	In response to the oversupply issue, a pivotal strategy involves the utilization of big data platforms to facilitate technological solutions that disseminate information across the pineapple supply chain. The primary objective is to improve the accuracy of market demand forecasting, enabling farmers to align their crop planning more efficiently with actual market conditions.

Conclusions

In this study, the analysis of flexibility performance in the pineapple supply chain clearly showed that pineapple farmers with GAP performed better than farmers without GAP. Additionally, the research identified the most important indicator, which is risk number 18 (uncertain changes in purchase price). This indicator hampers the flexibility of the supply chain's performance. Thus, pineapple farmers and relevant agencies must pay attention and find methods to eliminate the above indicator to increase efficiency in the supply chain. The result corresponds to analyzing the pineapple supply chain in Prachuap Khiri Khan, as mentioned. The market demand situation is the main issue in managing the supply chain and directly affects the purchase price.

Furthermore, the result of the risk assessment of pineapple farmers implemented both with and without GAP unidirectionally showed the risk score for five major risks, including risk numbers 2 (errors in forecasting and planting planning), 7 (lack of support for the production process development), 9 (severe drought or inadequate agricultural water supply), 16 (shortage of labor in the production process), and 18 (uncertain changes in purchase price). Additionally, the result of the risk assessment revealed two interesting observations. Pineapple farmers implemented with GAP effectively mitigated internal risks, including risk numbers 2, 9, and 16. Moreover, pineapple farmers who implemented GAP demonstrated increased awareness of external risks. This is evident in the risk assessment for risk numbers 7 and 18, which yielded higher risk scores compared to pineapple farmers without GAP.

As mentioned above, five significant risks within Thailand's pineapple supply chain were identified, consisting of forecasting errors, development shortages, water scarcity, labor shortages, and price uncertainties. These risks were used to create eleven strategies as follows: efficient loading and unloading equipment, queue management technology, technology and innovation, dealing with uncertain purchase prices, addressing water scarcity, handling labor shortages, establishing knowledge sharing centers, diversified distribution channels, coping with water shortages, replacing labor with technology, and utilizing big data for market demand forecasting. These strategies collectively will contribute to a more sustainable, efficient, and resilient Thailand's pineapple supply chain.

In addition to the study outputs, which encompass risk mitigation strategies and performance indicators for flexibility in the Thailand pineapple supply chain, the result of risk assessment from pineapple farmers with and without GAP can further extend the study towards an analysis of data sensitivity. Further studies, which focus on analyzing the perception of risks, found that pineapple farmers who implemented GAP had a higher probability or frequency of facing risks compared to farmers without GAP. This is an interesting issue that could lead to more specific risk mitigation strategies for pineapple farmers with GAP. Specifically, these strategies will motivate a shift towards cultivation, according to GAP.

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Ammonia Removal of Chicken Manure by Vacuum Stripping Technique for Sustainable Biogas Production in Chicken Farm

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Abstract

The objective of the research was to examine how the temperature, agitation rate, and duration of pretreatment process of chicken manure (CM) affect the efficacy of ammonia removal and biogas production. The CM was pretreated through vacuum thermal stripping in various conditions and subsequently anaerobic digested using biochemical methane potential (BMP) test. The findings indicated that vacuum thermal stripping technique was successful in removing ammonia from the CM. However, the potential for ammonia removal was also influenced by the conditions used in the pretreatment process. Pretreatment at 120°C with agitation at 50 rpm for 4 hr showed the highest ammonia removal (68.69%), which was significantly greater than pretreatment at 50°C and 85°C (23-44%). However, pretreatment at high temperature could lower biogas yield of pretreated CM samples. The biogas yield of CM sample pretreated at 120°C (272-277 NmL/gVS$_{added}$) was lower than that of pretreatment at 50°C and 85°C (484-517 NmL/gVS$_{added}$). When using the vacuum thermal stripping technique for application in biogas system, it is important to ensure that the conditions are appropriate for both removing ammonia and producing biogas.

Keywords : ammonia removal; chicken manure; vacuum stripping technique; biogas production; chicken farm

Introduction

A challenge for chicken farm owners that desire to manage their waste through anaerobic digestion (AD) process for generating biogas is due to a large amount of nitrogen especially in the form of organic and ammonia nitrogen in chicken manure (CM). Significant nitrogen content in CM could be toxic to the biogas system, lower the biogas yield, and subsequently lead to process failure [1, 2]. To mitigate this issue, substantial amounts of water is usually used for dilution to obtain a total solids (TS) content of 0.5-3.0% for efficient AD of the CM [3]. However, using large amounts of water for dilution affects sustainability of the process, creates extensive amount of wastewater, and requires large size of reactor for AD.

Pretreatment which aims at ammonia reduction would help to lessen ammonia toxic effect of the nitrogen rich material resulted in biogas production improvement in high solids content biogas system or dry AD or solid-state AD (SS-AD) [4]. The vacuum stripping technique could be one of the promising techniques for ammonia removal. Under vacuum condition at high temperature, the ammonia mass transfer increases and ammonia evaporation can improve.

Therefore, the overarching goal of this study was to investigate the feasibility of vacuum stripping pretreatment on biogas production improvement from CM. The specific objectives were (i) to evaluate the effects of pretreatment conditions, including temperature, agitation rate, and time, on ammonia removal efficiency, and (ii) to examine the biochemical methane potential (BMP) of the pretreated substrate.

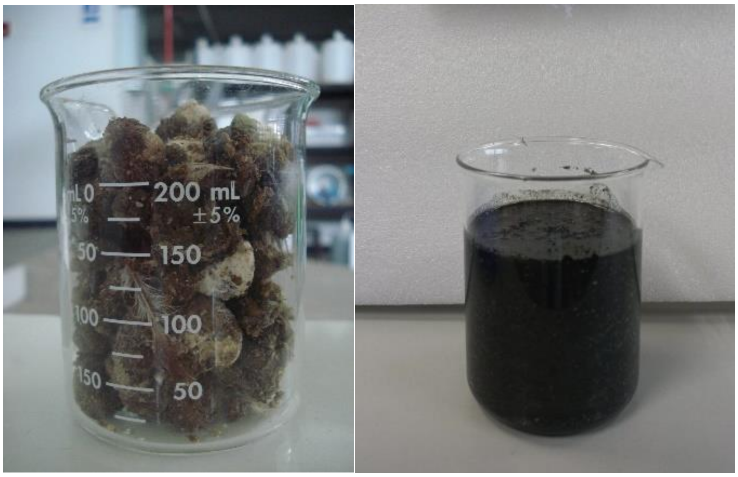
Materials and Methods

Chicken manure and seed inoculum

The CM and seed inoculum were obtained from anaerobic channel digester of R.P.M Farm & Feed, Chiang Mai, Thailand (Figure 1). The separated feathers and eggshells were used to prepare the CM. After being prepared, the CM was stored at 4°C until needed for further use, whereas the seed inoculum was filtered to remove the inert sludge. It was then incubated at 35±2°C for 7 d before being used. The dry matter (DM) content of the CM was 39.7%, the volatile solids (VS) content was 68.4% of the DM and the ammonia (NH_3) content was 1.7% of the DM.

Vacuum stripping unit

The vacuum stripping pretreatment process was controlled by a control panel, which regulated the temperature, agitation speed, and time of the 10 L stainless steel vacuum stirrer reactor (30 cm height and 20 cm diameter). The reactor was equipped with an impeller connected to a 120 W motor to offer agitation up to 200 rpm, and covered with a heating plate to heat the contents from 30°C to 150°C. In addition, it was connected to a particle trap and a vacuum pump to ensure efficient operation (Figure 2).



(a) (b)

Figure 1 The physical characteristics of (a) chicken manure (b) seed inoculum

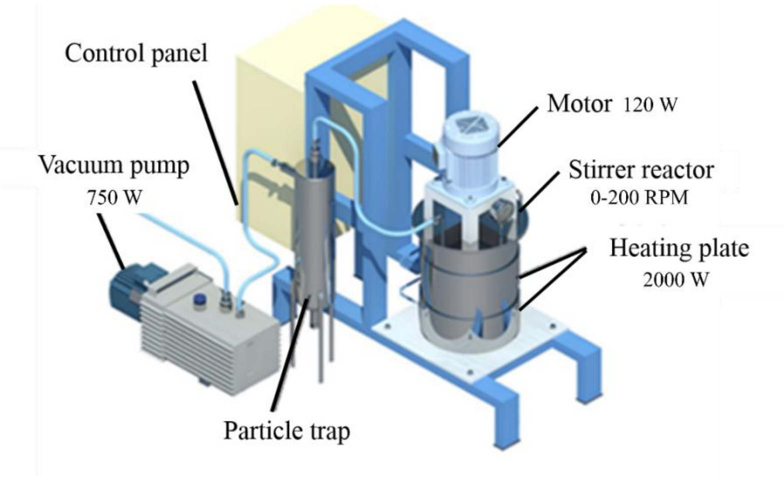


Figure 2 Vacuum stripping unit

Vacuum stripping pretreatment study and BMP test

This study aims to evaluate the optimal pretreatment conditions for ammonia removal in the CM using a two-level full factorial design of experiment and the Central Composite Design (CCD). In the pretreatment process, the reactor containing 2 kg of CM was heated at temperatures ranging from 50-120°C, agitated at a rate of 50-100 rpm, and exposed to a vacuum for 1-4 hr. The total kjeldahl nitrogen (TKN), total solids (TS), volatile solids (VS) and ammonia (NH_3) were measured from the sample both before and after undergoing pretreatment. The pretreated sample that showed the highest level of ammonia removal was chosen for further investigation. Both pretreated and non-pretreated samples were diluted with water in ratios of 1:2 and 1:5 (w/v) and subjected to BMP test followed by modified VDI4630 [6]. To study the effect of ammonia dilution on biogas production rate. It can be used to develop wet or dry biogas production systems for chicken farms.

The batch BMP test was done in triplicate with a 1,250 ml bottle (working volume 400 ml). In each bottle, 300 ml of inoculum seed and 100 ml of the CM sample were added before being sealed with a rubber stopper. To create an anaerobic environment, nitrogen gas was purged into the bottles for a period of three minutes. The bottles were subsequently placed in a temperature-controlled room (35±2°C). Biogas production was measured using pressure meter (KIMO Mode MP120, France) and the volume of biogas produced was calculated and reported under standard temperature and pressure condition as the biogas yield (NmL/gVS_{added}). In addition, the composition of the biogas was observed using a portable gas detector (Gas data Model GFM406, UK) when the relative gas pressure inside the bottles exceeded 300 mbar. The standard method [5] was employed to evaluate the parameters of pH, VS, volatile fatty acid (VFA), and alkalinity (Alk) in the samples before and after the BMP test.

Statistical analysis

The data is presented as mean values and their corresponding standard deviations. One-way ANOVA was used to analyze the data, and Tukey test was employed to determine significant differences among the means at a 95% confidence level.

Results and Discussion

The physical characteristics of the pretreatment chicken manure were performed on the CM samples, which were presented in Table 1. The effect of different pretreatment conditions on ammonia removal efficiency was also studied and it was found that the temperature and time of vacuum pretreatment had a significant impact on ammonia removal. Additionally, Figure 3 illustrated the physical characteristics of the pretreatment chicken manure. The optimal pretreatment condition was found to be 120°C, 50 rpm for 4 hr, resulting in a maximum ammonia removal of 70% and the organic (VS) removal of 19.8%. As excessive heat can trigger the decomposition of organic matter during the process, leading to negative VS removal. Overall, it is important to carefully evaluate all the options and consider the long-term costs and benefits of each alternative energy source to determine the most effective and sustainable approach for conditioning the CM.

The BMP test for non-pretreated and pretreated CM at two different CM and water ratios (1:2 and 1:5 (w/v)) and the resulting biogas yields are shown in Table 2. It was found that pretreatment caused significant reduction on the biogas yield. This could be due to excessive heating and vacuum time resulted in significant drop in organic matter of the CM (19.8%). It was found that pretreatment caused a significant reduction in biogas yield at 95% confidence. It could be due to excessive heating and vacuum time. As a result, the organic matter in the CM decreased. According to the research by Raju *et al.* [7], thermal pre-treatment at 225°C for 15 min reduced the BMP of dewatered CM by 18%. However, the study also found that at lower temperatures, there were no significant changes in the BMP.

Table 1 Results of analyses performed on the pre-treated and non-pretreated CM

Item	Temp (°C)	agitation rate (rpm)	Time (hr)	DM (%)	VS (%DM)	NH_3 (g/kgDM)	TKN (g/kgDM)	NH_3 removal (%)	VS removal (%)
1	50	50	1	45	72	10.26	47.42	37.99	4.94
2	120	50	1	84	51	5.48	54.58	66.87	-25.30
3	50	100	1	49	71	9.39	57.35	43.25	3.96
4	120	100	1	62	72	10.22	64.93	38.21	5.50
5	50	50	4	48	71	10.38	37.32	37.25	3.81
6	120	50	4	94	55	5.18	42.29	68.69	-19.82
7	50	100	4	47	71	9.34	49.44	43.56	4.39
8	120	100	4	82	65	8.60	55.14	48.01	-4.28
9	85	75	2.5	57	68	10.34	55.28	37.49	-0.47
10	85	75	2.5	73	66	10.07	47.52	39.12	-3.39
11	85	75	2.5	66	66	9.61	58.32	41.92	-3.40
12	85	75	2.5	62	69	10.75	47.83	35.01	0.31
13	27.8	75	2.5	44	71	10.05	53.06	39.28	3.17
14	142.1	75	2.5	77	65	8.22	49.60	50.30	-4.57
15	85	34.1	2.5	60	67	11.49	51.57	30.56	-1.77
16	85	116	2.5	53	69	10.48	42.82	36.64	1.06
17	85	75	0.05	44	72	10.67	51.24	35.54	4.53
18	85	75	4.9	63	69	11.80	73.91	28.69	0.95
19	85	75	2.5	67	66	10.09	56.10	39.05	-3.01
20	85	75	2.5	59	65	9.97	55.21	39.73	-5.65
non-pretreated CM				40	68	16.55	52.16	-	-

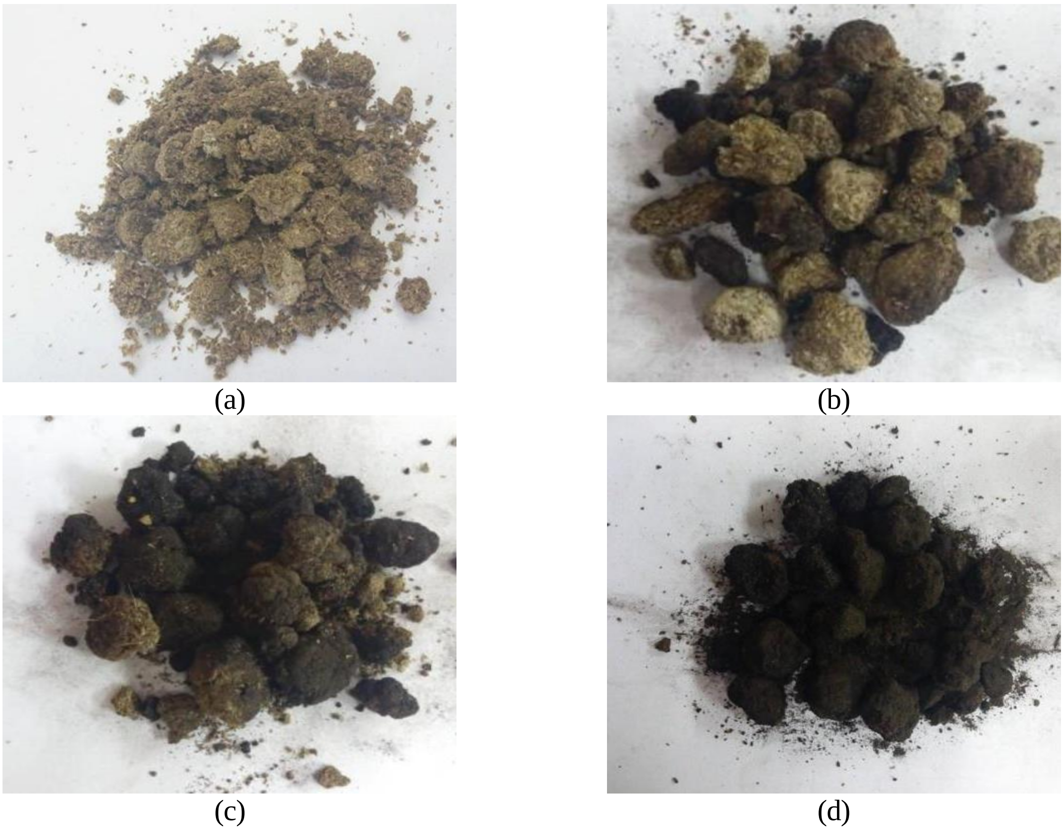


Figure 3 Physical characteristics of pretreatment chicken manure (a) CM pretreated of 50°C (b) CM pretreated of 85°C (c) CM pretreated of 120°C and (d) CM pretreated of 142°C

Table 2 Biogas yield from CM of non-pretreated and pretreated samples at different dilution rates

Samples		Biogas yield (NmL/gVS_{added})	Biogas yield efficiency (%)
CM: water (1:2) %w/v	CM non-pretreated	469^{A} ±28	-
	CM pretreated 50°C 100 rpm 4 hr	484^{A} ±15	3.3
	CM pretreated 85°C 75 rpm 2.5 hr	495^{A} ±31	5.7
	CM pretreated 120°C 50 rpm 4 hr	272^{B} ±5	-42.0
CM: water (1:5) %w/v	CM non-pretreated	492^{A} ±21	-
	CM pretreated 50°C 100 rpm 4 hr	517^{A} ±4	5.1
	CM pretreated 85°C 75 rpm 2.5 hr	517^{A} ±14	5.2
	CM pretreated 120°C 50 rpm 4 hr	277^{B} ±12	-43.6

The vacuum stripping technique allowed for an increase in biogas yield (Table 2) by 3.3% to 5.7% for CM pretreated 50°C to 85°C, respectively, compared to chicken manure without pretreatment. Increasing the water diluted from 1:2 %w/v to 1:5 %w/v resulted in and increase in biogas production by 5.1% and 5.2%. But the CM pretreated 120°C 75 rpm 4 hr: water (1:2) %w/v and the CM pretreated 120°C 75 rpm 4 hr: water (1:5) %w/v were no significant differences in biogas yields ($P<0.05$). However, there was a significantly lower difference of biogas production compared to other experiments. The results revealed that overheating period during manure conditioning can have an impact on the biogas potential of the substrate. It is recommended that the pretreatment CM at high temperature should heating time less than 4 hours to avoid negative effects on biogas potential. These results indicate that factors related to CM pretreatment to reduce water scarcity for biogas production of chicken farms. It was shown that the pretreatment of chicken manure can reduce water dilution.

In Table 2, the specific biogas yields achieved from the pretreated CM under these conditions (85°C 75 rpm 2.5 hr and 50°C 100 rpm 4 hr in a dilution ratio of 1:5 (w/v) were 517±4 and 517±14 NmL/gVS_{added}, respectively. Lower temperature treatment of CM may be beneficial in biogas yield because it can help to preserve the microbial population that is responsible for breaking down the organic matter. This finding was in close agreement with Konkol *et al.* [8], which reported that extracting excess nitrogen from chicken manure through water extraction within a temperature range of 20°C to 60°C resulted in a notable enhancement of biogas production, ranging from 16% to 45%, when compared to untreated manure.

After the fermentation process were completed, the samples' chemical characteristics were examined as depicted in the table 3. This time, there was no indication that ammonia had a detrimental effect on bacteria, resulting in VFA and Alk values that were within the acceptable range for microbes that produce biogas. For a general stable fermentation process, it is assumed that the ratio of VFA/Alk should not exceed 0.4. In this study, the ratios of VFA/Alk were between 0.12 to 0.16, and thus the fermentation process can be regarded stable. The VS removal efficiency was found to range from 17.7-41.4% and 20-36.8% at a dilution rate of CM: water (1:2) %w/v and (1:5) %w/v, respectively.

Table 3 Chemical analysis of samples after BMP test

Parameters		pH	VS (mg/L)	VFA ($mgCH_3COOH/L$)	Alk ($mgCaCO_3/L$)	VS removal (%)
CM: water (1:2) %w/v	Non-pretreated	7.2±0.0	18,713±202	863±38	6,883±395	37.2±0.7
	50°C 100 rpm 4 hr	7.3±0.1	19,032±532	975±80	7,721±157	41.4±1.6
	85°C 75 rpm 2.5 hr	7.5±0.1	26,843±705	1,544±178	11,474±354	40.7±1.6
	120°C 50 rpm 4 hr	7.4±0.1	39,967±875	1,175±65	9,982±21	17.7±1.8
CM: water (1:5) %w/v	Non-pretreated	7.0±0.0	15,750±350	513±23	4,137±230	24.6±1.7
	50°C 100 rpm 4 hr	7.1±0.1	16,307±498	726±56	4,454±270	27.6±2.2
	85°C 75 rpm 2.5 hr	7.3±0.1	19,757±215	846±161	6,142±58	36.8±0.7
	120°C 50 rpm 4 hr	7.2±0.1	26,807±289	765±77	6,122±63	20.0±0.9

Conclusions

Using vacuum stripping as a pretreatment method on CM had a significant effect in removing ammonia and producing biogas. The reduction of ammonia content through vacuum stripping can improve the stability of the biogas production process by preventing the buildup of toxic substances that can inhibit the growth of microorganisms involved in the biogas production. Moreover, the use of waste heat to power the vacuum stripping process can further improve the efficiency and sustainability of the production system by reducing the cost of pretreatment of CM. By adopting such integrated approaches, farms can optimize the use of resources, minimize waste, and reduce their environmental impact, while also generating renewable energy from CM. Moreover, the use of waste heat to power the vacuum stripping process can further improve the efficiency and sustainability of the production system by reducing the cost of pretreatment of CM. By adopting such integrated approaches, farms can optimize the use of resources, minimize waste, and reduce their environmental impact, while also generating renewable energy from CM.

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Effect of Covid-19 on Healthcare Waste and Waste-Related the Pandemic: A case study in Nakhon Nayok province, Thailand

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Abstract

In response to the COVID-19 pandemic, public health measures have led to a significant increase in healthcare waste (HW) and household hazardous waste (HHW) globally. HW, including masks, gloves, and other infectious materials from disease treatment, and HHW, such as paint, batteries, personal cleansers, cleaning products, and hand sanitizer containers, have posed new challenges in waste management. This study, conducted in Nakhon Nayok province, Thailand, fills a critical gap in understanding the extent and nature of this waste surge. From December 2020 to June 2021, we quantitatively analyzed the HW and HHW, finding that HW related covid-19 accounted for 0.03% (43.26 kg/day) and HHW related covid-19 for 3.02% (4.37 tons/day) of the total waste stream. Our findings reveal the critical necessity for comprehensive waste management interventions, particularly the proper segregation of HW and HHW from household waste, to mitigate contamination and infection risks. The study emphasizes the need for enhanced governmental action in waste management infrastructure, including public awareness campaigns on waste separation and the implementation of specialized bins for HW and HHW in residential and community areas. Additionally, it highlights the importance of developing a robust policy framework in Thailand to address the challenges of pandemic-related waste surge. The research points to future avenues exploring the environmental and public health ramifications of COVID-19 waste, especially in understanding how various communities adapt their waste management practices during public health crises. Insights from such studies could be instrumental in refining waste management practices, making them suitable for different socio-economic contexts and improving overall public health outcomes.

Keywords : COVID-19; Healthcare Waste; Pandemic Waste; Waste Characterization; Infectious Waste

Introduction

In December 2019, China reported a cluster of pneumonia cases in Wuhan, later identified as caused by SARS-CoV-2 [1, 2]. The virus quickly spread globally, affecting over 200 million people [3]. During the period of our study from December 2020 to June 2021, Thailand was during its fourth COVID-19 wave, with daily confirmed cases at times exceeding 20,000 [4]. Vaccines have become crucial in mitigating the impact of the virus, reducing severe illness and hospitalization rates [5-7]. Both international organizations like the World Health Organization and local authorities in Thailand have emphasized the importance of rapid testing for SARS-CoV-2 [8, 9]. Antigen rapid diagnostic tests (Ag-RDT) are commonly used in Thailand due to their speed, cost-effectiveness, and ease of administration [10, 11]. The pandemic has led to increased usage of protective measures such as alcohol gel, gloves, and facemasks [12]. This surge has contributed to a significant rise in healthcare waste (HW) and poses environmental challenges [12-17]. The Thai Ministry of Public Health estimates that 1.8 million pieces of used masks are converted into HW daily, not including other items like gloves and personal protective equipment (PPE) [18-20]. In Thailand, waste is categorized into four types: municipal, industrial, household hazardous waste (HHW), and HW [21-23]. While healthcare facilities manage HW effectively, household waste remains a concern due to a lack of proper tracking and disposal systems [24-26]. Nakhon Nayok, one of Thailand's 29 Dark-red provinces, faces challenges in managing HW effectively. This study aims to assess the generation and management of healthcare waste (HW) and household hazardous waste (HHW) in Nakhon Nayok during the COVID-19 pandemic and proposes effective management strategies to address these challenges.

Materials and Methods

Study site

The study was conducted in Nakhon Nayok province, located in eastern Thailand (Latitude: 14° 12' 16.67" N; Longitude: 101° 12' 46.62" E). The province covers 2,122 km^2 with an approximate population of 260,081 (123 person/km^2) individuals residing in 101,547 households. Nakhon Nayok was selected as the study site due to its designation as one of the Dark-red provinces, indicating a high level of COVID-19 transmission and stringent public health control measures. In Nakhon Nayok Province, waste management responsibilities, particularly during the COVID-19 outbreak, fall under the jurisdiction of local government organizations. As mandated by Thai law, infectious waste must be disposed of in red trash cans. To manage the increased volume of infectious waste during the pandemic, Nakhon Nayok Province has implemented measures aligned with national protocols, involving the segregation and destruction of such waste. The province's diverse population and household structures provide a representative sample for assessing the generation and management of healthcare waste (HW) and household hazardous waste (HHW) during the pandemic [27].

Study design

This research employed a stratified random sampling method to analyze the impact of the COVID-19 pandemic on household hazardous waste (HHW) and healthcare waste (HW) generation from December 2020 to June 2021. The study encompassed three administrative levels—Municipalities, Subdistrict Municipalities, and Administrative Organizations—with a sample size of 90 households, 30 from each level. Bi-monthly garbage collection was conducted on randomly selected days in the second and fourth weeks of each month, resulting in 14 collection rounds over the study period. The waste was categorized into 13 types—Paper, Plastics, Glass, Wood, Metals and Aluminum, Food, Household, Hazardous Waste, Healthcare Waste, E-Waste, Yard Waste, Textile, Leather, and Rubber—and further subcategorized into COVID-19-related items (e.g., hand sanitizer containers, sanitizing wipes, used face masks, gloves) and non-COVID-19-related items (e.g., paint, batteries, gauze, bandages, medicine) for detailed analysis.

Data Validity and Reliability

For validity, we employed well-established data collection methods and ensured that our tools for categorizing and measuring waste were thoroughly tested and validated. Our team of data collectors received comprehensive training to maintain accuracy in data recording.

Statistical analyses

Data collected from the 90 households were subjected to descriptive statistical analysis to summarize and interpret the trends in waste generation and categorization. The analyses were performed using STATA software, version 10 (StataCorp LP). Specific statistical measures such as mean, median, standard deviation, and frequency distribution were calculated to provide a comprehensive overview of the data.

Ethical approval

The Srinakharinwirot University ethics committee for human research reviewed and approved the study (registration SWUEC-415/2563E).

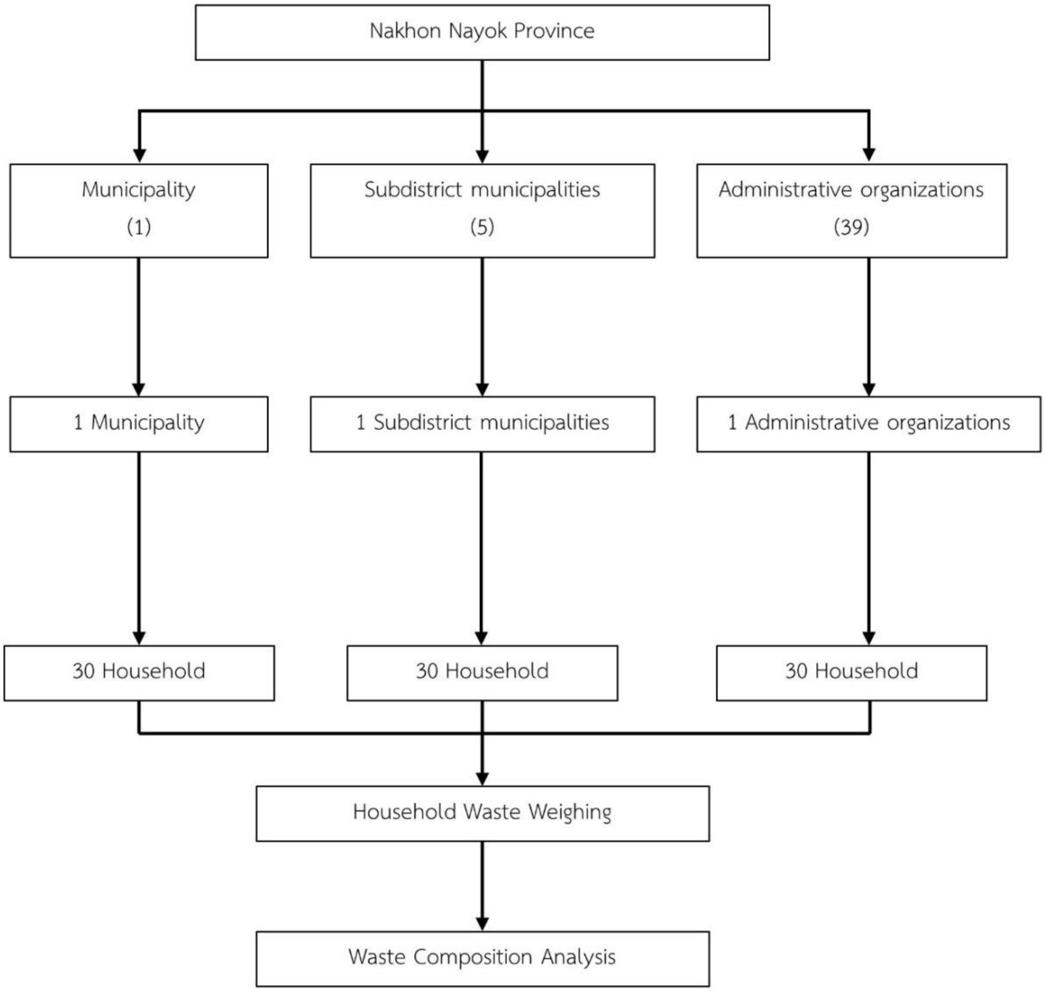

Figure 1 Flowchart of data collection and analysis

Results and Discussion

Household and Healthcare Waste Composition

Our study found that household hazardous waste (HHW) and healthcare waste (HW) accounted for 16.4% of the total waste produced by 90 households in Nakhon Nayok province. Of this, HHW comprised 12.03%, predominantly non-COVID-related, while HW formed a smaller portion (4.35%), with HW related covid-19 (0.03%) and HHW related covid-19 (3.02%). Most of the HHW related to covid-19 occurred in municipalities, subdistrict municipalities, and administrative organizations, respectively. In contrast, the majority of HW related covid-19 was generated predominantly in subdistrict municipalities, followed by administrative organizations and municipalities. These findings underscore the necessity of segregating HHW and HW from other wastes, as emphasized by existing literature [28]. The pandemic's influence is evident in the composition of waste, with items like hand sanitizers, sanitizing wipes, and used face masks becoming significant components.

Table 1 Healthcare waste and household hazardous waste composition in each administrative organization level

Type of household waste	Weight and percentage (kg and percentage)			
	Overall	Municipality	Subdistrict municipalities	Administrative organizations
Plastics	450.21 (25.14)	138.69 (27.74)	94.38 (18.32)	217.14 (28.00)
Papers	124.00 (6.92)	22.60 (4.52)	32.20 (6.25)	69.20 (8.92)
Wood	11.72 (0.65)	0.50 (0.10)	1.98 (0.38)	9.24 (1.19)
Glass	72.00 (4.02)	3.80 (0.76)	20.80 (4.04)	47.40 (6.11)
Metal	35.00 (1.95)	1.20 (0.24)	4.80 (0.93)	29.00 (3.74)
Food	648.90 (36.24)	215.06 (43.02)	258.72 (50.22)	175.12 (22.58)
Total of HHW	215.42 (12.03)	33.66 (6.73)	43.84 (8.51)	137.92 (17.78)
HHW related covid-19	54.02 (3.02)	26.06 (5.21)	16.64 (3.23)	11.32 (1.46)
HHW non-related covid-19	161.40 (9.01)	7.60 (1.52)	27.20 (5.28)	126.60 (16.32)
Total of HW	78.01 (4.35)	54.64 (10.93)	13.46 (2.61)	9.91 (1.28)
HW related covid-19	0.61 (0.03)	0.04 (0.01)	0.26 (0.05)	0.31 (0.04)
HW non-related covid-19	77.40 (4.32)	54.60 (10.92)	13.20 (2.56)	9.60 (1.24)
Electronic	1.20 (0.07)	0 (0)	0 (0)	1.20 (0.15)
Yard	88.00 (4.91)	27.8 (5.56)	27.00 (5.24)	33.20 (4.28)
Textile	30.40 (1.70)	2 (0.40)	13.00 (2.52)	15.40 (1.99)
Rubber	29.00 (1.62)	0 (0)	3.40 (0.66)	25.60 (3.30)
Leather	6.80 (0.38)	0 (0)	1.60 (0.31)	5.20 (0.67)
Total	1790.66 (100)	499.95 (100)	515.18 (100)	775.53 (100)

COVID-19-Related Waste at Different Administrative Levels

Our analysis of COVID-19-related waste at the administrative level revealed insightful patterns. Notably, while the overall proportion of healthcare waste (HW) related to COVID-19 was relatively minimal, it was the administrative organizations that generated the highest proportion at 0.04%, followed by subdistrict municipalities at 0.05% and municipalities at 0.01%. On the other hand, household hazardous waste (HHW) related to COVID-19 was more significant, with municipalities showing the highest proportion at 3.02%. This disparity in waste generation across different administrative levels might be attributed to variations in public health awareness and adherence to safety measures. For instance, the higher proportion of COVID-19-related HHW in municipalities could indicate more rigorous practices in personal protective equipment use among the general population. In contrast, the pattern observed in HW, especially in administrative organizations and subdistrict municipalities, might reflect different operational dynamics in healthcare settings. The findings of Techasatian et al. regarding the extended use of face masks among hospital workers [29] resonate with our observations, suggesting a possible trend of reusing protective gear in professional settings. This practice could be a result of heightened health awareness or resource constraints, which aligns with the varying levels of COVID-19-related waste generation we noted. Such trends underscore the need for tailored public health messaging and resource allocation strategies to ensure effective waste management in the context of a pandemic.

Income and Healthcare Product Purchasing Decisions

Our research also delved into the relationship between income levels and the purchase of healthcare products, echoing the findings of Laaksonen et al. [30]. We observed that higher-income areas like municipalities tended to generate more COVID-19-related HW, indicating a correlation between income and expenditure on WHO-endorsed healthcare products, which aligns with the broader trend that people with higher incomes generally have greater purchasing power. This is particularly relevant for healthcare products like hand sanitizers, alcohol gel, and face masks, essential in the context of the pandemic. Supporting this observation, a review of existing literature corroborates our findings. Numerous studies have indicated that higher income levels often translate to increased expenditure on healthcare products [31, 32]. These trends are consistent with our observations in Nakhon Nayok province, where wealthier municipalities showed higher consumption and, consequently, higher disposal rates of COVID-19-related HW. This correlation underscores the socioeconomic dimensions of pandemic response, suggesting that income levels play a significant role in determining how communities engage with health protective measures and manage related waste. This trend is further supported by the research of Intarasaksit and Pitaksanurat, which highlights that populations in municipalities with higher income levels tend to have greater purchasing power. This increased capacity to buy healthcare products, such as hand sanitizers and face masks, leads to a higher generation of HHW related to COVID-19 in these areas compared to others with lower income levels [23]. Consequently, this demographic is likely to invest more in protective measures like hand sanitizers and sanitizing wipes, as seen in the waste composition. Considering our findings, higher-income areas, which tend to produce more solid waste include COVID-19-related healthcare waste, could significantly benefit from targeted waste management strategies [33]. These might include developing incentives for reducing healthcare waste, promoting the use of reusable PPE where appropriate, and fostering partnerships with local healthcare providers for more efficient waste segregation and disposal, especially during pandemic peaks. In contrast, lower-income areas could significantly benefit from policies that increase investment in waste management infrastructure, educational programs on proper waste disposal, and improved access to essential healthcare and sanitation products.

Implications for Public Health Policy and Outreach

Our findings on income-related disparities in COVID-19 waste generation have critical implications for public health policy and outreach. To address these disparities, targeted interventions are necessary. In higher-income areas, where higher waste generation was observed, public health campaigns should focus on promoting sustainable waste practices and the importance of responsible disposal. Conversely, lower-income areas may require more support in infrastructure development and access to waste disposal facilities. Policymakers should consider these disparities when formulating waste management strategies, ensuring that interventions are adapted to the specific needs of each community. Additionally, training healthcare practitioners in waste segregation and management tailored to their area's socioeconomic context can further enhance the effectiveness of these strategies. Our study's findings have significant implications for public health policy and marketing strategies. The evident income-related disparities in purchasing and usage of healthcare products suggest that targeting higher-income individuals with public health interventions might yield more substantial compliance and uptake. This approach could be instrumental in managing healthcare waste and enhancing public health measures, especially in a pandemic context [34-36]. Furthermore, establishing a policy for managing infectious waste, including waste generated during health crises, is both essential and beneficial. Such a policy should not only focus on educating the public about separating infectious waste but also ensure effective public relations to garner cooperation. However, this alone is insufficient. It is imperative to implement rigorous monitoring systems and to enforce the segregation of infectious waste from other waste types. Additionally, providing clear guidelines on correct separation methods is crucial for the formulation of an effective policy [17].

Conclusion

Our study effectively addressed our stated aim of assessing the generation and management of healthcare waste (HW) and household hazardous waste (HHW) in Nakhon Nayok during the COVID-19 pandemic and proposing effective management strategies. This research highlights that while COVID-19-related healthcare waste (HW) forms a relatively small proportion of the total waste stream in Nakhon Nayok province, its impact is nonetheless significant. Constituting about 0.03% (43.26 kg/day) of household hazardous waste (HHW) and 3.02% (4.37 t/day) of general HW, this pandemic-related waste, including masks, hand sanitizers, and sanitizing wipes, points to an upward trend in HW and HHW generation. This trend is not only a reflection of the ongoing battle against COVID-19 but also a call to action for more effective waste management strategies. The increase in COVID-19-related waste necessitates urgent and comprehensive waste management interventions. Essential to these interventions is the proper segregation of HW and HHW from regular household waste. This segregation is crucial to mitigate the risks of contamination and infection, protecting not only households but also the workers involved in waste management. Our study underscores the need for governmental action in enhancing waste management infrastructure. This includes public awareness campaigns focused on the importance of proper waste separation and the introduction of specialized bins for HW and HHW in both households and community spaces. Furthermore, our findings advocate for the development of a robust policy framework in Thailand to tackle the challenges presented by the surge in pandemic-related waste. Future research should aim to delve deeper into the environmental and public health ramifications of COVID-19 waste, focusing particularly on understanding how different communities adapt their waste management practices in response to public health crises. Such studies could offer valuable insights that would help in refining and improving waste management practices, tailoring them to varying socio-economic contexts and enhancing overall public health outcomes.

Limitations of the Study

This study recognizes certain limitations. The timeframe, covering December 2020 to June 2021, specifically focuses on the early stages of the pandemic. This period may not fully capture the evolving nature of waste management practices beyond these months, limiting the scope of long-term trend analysis.

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Evaluation of Land Use Effects on Surface Water Quality in the Upper Yom River Basin, Phayao Province

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Abstract

Although water quality in Upper Yom River Basin, Part 1, has been monitored, it has not yet covered land use patterns. Therefore, this study aims to monitor and evaluate surface water quality from land use in Upper Yom River Basin, Part 1, Pong District, Phayao Province, by classifying land use in order to collect specific water samples and analyze them. Physicochemical and biological water quality found that water quality in lower Yom watershed was mostly within the water quality standards for surface water sources, with the highest TCB and FCB detected in dense residential areas. As for the rural conservation and agricultural areas along the Khuan, Ngim, and Yom rivers, TCB and FCB were detected in low amounts, but there were high levels of NO_3-, indicating the result of farmers' use of chemical fertilizers and surface runoff into natural rivers. This affects the assessment of the overall status of Upper Yom River Basin, Part 1, at the Warning level (mean score = 2.92), showing that the water quality has begun to deteriorate from its common condition, requiring monitoring of the EC, TCB index., Turbidity, FCB and PO_4^{3-} periodically and selectively to keep up to date with situations that may occur in the future.

Keywords : Upper Yom River Basin; Surface Water quality; Water resources

Introduction

The Upper Yom River Basin is 1 of 11 sub-watersheds of the Yom Watershed located in the northern region of Thailand. It has an area of 2,113 sq.km. Its topography is high mountains with narrow plains near the river. It originates from Doi Khun-Yuam in Phi-Pan-Nam mountain range, located in Pong District, Phayao Province [1]. The Upper Yom River Basin, Part 1, in addition to being a risky area due to regular flooding or drought problems, encroachment of forests for agriculture and tourist attractions has also been found. In particular, growing monoculture crops causes soil erosion in the slopes and riverbanks including the problem of chemical contamination in water sources. This is caused by the use of chemicals such as chemical fertilizers, pesticides and herbicides in agriculture and washes into natural water sources. Until causing water pollution problems, affecting water shortages for consumption and subsequent consumption [2]. From annual report of state of surface water quality 2023, it was found that the overall water quality of Yom river is deteriorated with an average Water Quality Index (WQI) value is of 60.16 all year which should be monitored of dissolved oxygen (DO), Biochemical Oxygen Demand (BOD), Total Coliform Bacteria (TCB) and Fecal Coliform Bacteria (FCB) due to low water volume and slow flow as well as surrounding areas along the river are communities and agricultural fields (Environment and Pollution Control Office 4, 2023). Especially, in areas with expanding population, agricultural production, construction and urbanization as well as human activities soil erosion is the major problem [3-5]. Erosion causes both on-side and off-side effects on land and also on water bodies thereby affecting its quality [6]. It shows that changes in area conditions or land use have an impact on water quality. Therefore, this study aims to monitor and evaluate surface water quality from land use in

Upper Yom River Basin, Part 1, Pong District, Phayao Province.

Methodology

This research was designed water sampling twice a year during rainy (May 2022) and dry seasons (November 2022). Then, water samples were randomly collected using the grab sampling method and the water samples were maintained according to the guideline of Pollution Control Development (2010) for physicochemical and biological properties analysis according to APHA method (1992) [7] and US.EPA (1971) [8]. (Table 1)

Sampling points were determined from the classification and size of land use in Upper Yom River Basin, Part 1 using the Q-GIS 3.30.1system (GNU General Public License) and using land use data sets from the Department of Public Works and Town & Country Planning which is divided into 8 types: Y1: rural and agricultural land, Y2: rural and agricultural conservation land in Khuan Sub-Watershed, Y3: rural and agricultural conservation land in Ngim Sub-Watershed, Y4: rural and agricultural conservation land in Yom Sub-Watershed, Y5: less dense residential areas, Y6: medium-density residential areas, Y7: very dense residential areas and Y8: government agency offices and commercial areas (Figure 1).

Field measurements

T were measured with an APHA, AWWA, WEF (2012), 2550B and EC were measured with an APHA, AWWA, WEF (2012), 2520B, pH with a standard method for the examination of water and waste water (APHA, AWWA, WEF, 22nd Ed., 2012 Part 4500-H+), Tb with a APHA, AWWA, WEF (2012), 2130B. Instruments were calibrated prior to use according to the manufacturer's directions.

Chemical and biological analysis

BOD5 was determined as the difference between initial and 5-day oxygen concentrations in bottles assayed by APHA, AWWA, WEF (2012), 5210-BOD G, B., Total Phosphate was assayed by persulfate digestion and the ascorbic acid method (APHA, AWWA, WEF (2005), 4500-P-E). TSS were assayed by filtering a suitable amount of sample through a pre combusted GF/C glass fiber filter according to standard methods (APHA, AWWA, WEF (2012), 2540D). All samples were pre-treated with HNO_3 according to standard methods (APHA, AWWA, WEF (2012), 3030 E). Nitrate-Nitrogen was determined by APHA, AWWA, WEF (2005), 4500 NO^-_3. We use standard methods, EPA 507 by GC-FPD and CG/μ-ECD. Total coliforms and Fecal coliforms were assayed according to standard methods for examination of wastewater (APHA, AWWA, WEF, 21st Ed., 2005-part 9221 A-C, E-F part 9225 D) [9].

Water quality assessment using the Water Quality Index

For the criteria for each index studied Water quality standards have been applied to surface water sources that are not seawater according to environmental quality standards set by the Office of the Commission national environment (1994) [10]. To see the overall of the water quality of Upper Yom River Basin, Part 1. A scoring method for each index was used according to the score criteria used to evaluate the physical and chemical properties status by applying the evaluation criteria from the Huai Bong River Basin. Phu Wiang District, Khon Kaen Province of the field of watershed management Department of Conservation Science Faculty of Forestry, Kasetsart University, 2005 (quote in Ananya, 2015) [9]. Evaluation with water quality index separately consider each aspect as follows:

(1) The criteria used for evaluation Physical properties include water temperature, Turbidity, and Total Suspended Solids and Electrical Conductivity (Table 1).

(2) The criteria used for evaluation Chemical properties include BOD pH Total Phosphate and NO_3 (Table 2).

(3) The criteria used for evaluation include coliform, total bacteria and fecal coliform bacteria (Table 3).

Table 1 Criteria used to evaluate the physical properties status

Status	Scores	Temperature C	Turbidity (mg/l)	TSS (mg/l)	EC (µs/cm)
Nature	4	20-35	0-25	<500	<150
Warning	3	15-19.9, 35.1-37.9	26-50	500-1,000	150-300
Risky	2	10-14.9, 38-40.9	51-100	1,000-1,500	300-600
Crisis	1	<10, >40	>100	>1,500	<600

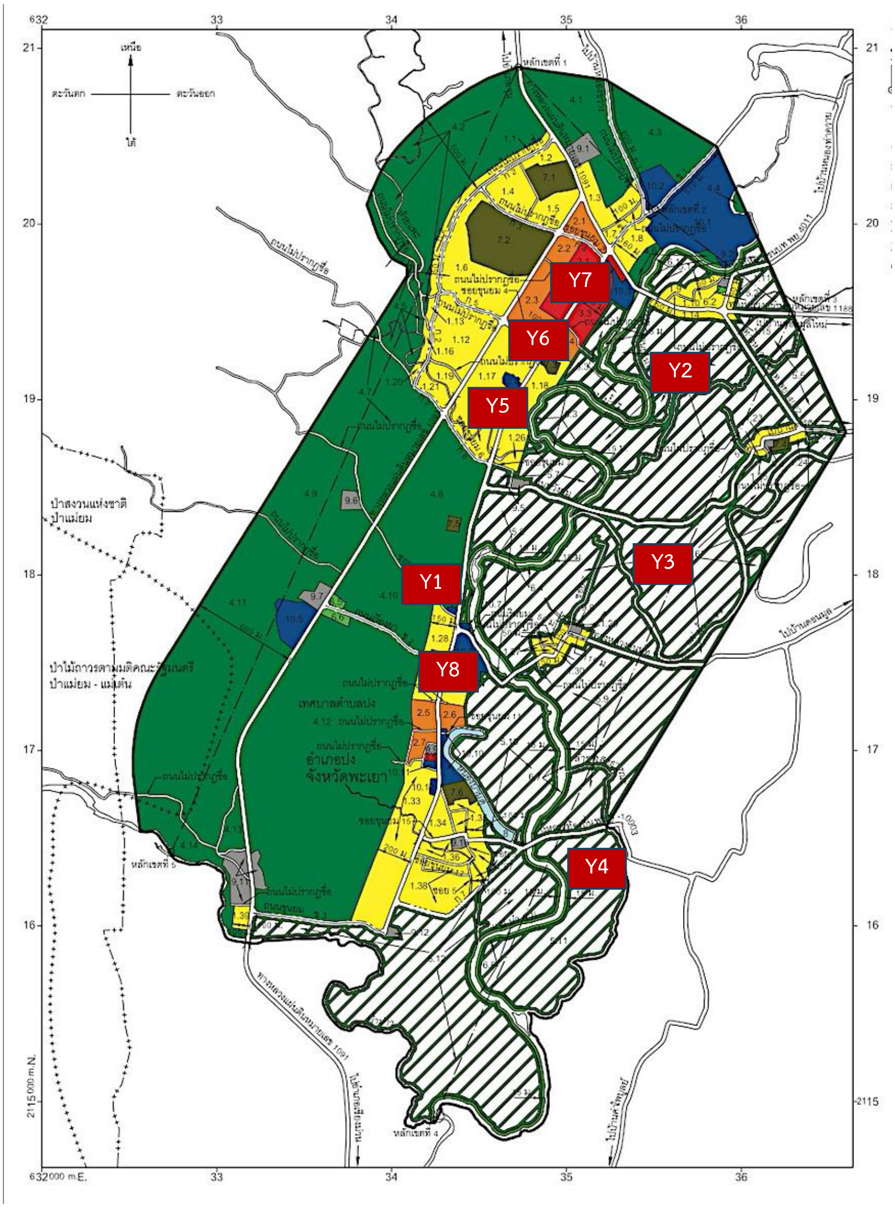

Figure 1 Map of water sampling sites in Upper Yom River Basin, Part 1
Source: Department of Public Works and Town & Country Planning, 2023

Table 2 Criteria used to evaluate the chemical water quality status

Status	Scores	pH	BOD (mg/l)	NO_3 (mg/l)	Total P (mg/l)
Nature	4	5-9	<1.5	<5	<0.1
Warning	3	4-5, 9-10	1.5-2	5-5.25	0.1-0.125
Risky	2	3-4, 10-11	2-4	5.25-5.5	0.125-0.15
Crisis	1	<3, >11	>4	>5.5	>0.15

Table 3 Criteria used to evaluate the biological water quality status

Status	Scores	Total coliform bacteria (MPN/100ml)	Fecal coliform bacteria (MPN/100ml)
Nature	4	0-2,500	0-400
Warning	3	2,500-5,000	400-800
Risky	2	5,000-10,000	800-1,600
Crisis	1	>10,000	>1,600

Then take the average of upper Yom River Basin, Part 1 at each station from Y1 to Y8, compare the scoring criteria and find the average. The total average obtained will be compared with Table 4 to lead to considering the status of water quality in the upper Yom River Basin, Part 1, and leading to the creation of further conservation guidelines.

Result and Discussion

Results of monitoring and evaluating surface water quality in the upper Yom watershed are shown in Table 5-7.

The results of the physicochemical and biological water quality examination found that water quality in the lower Yom Watershed was mostly within the water quality standard for surface water sources, except for FCB (4,500 MPN / 100 mL) that was detected in areas where land use was for residential density (Y7) exceeds the standard limit of 4,000 MPN / 100 mL and corresponds to the highest amount of TCB found (Table 3). This indicates that surface water in that area is not safe and may be contaminated with pathogens because FCB can only be found in the digestive system and excretions of warm-blooded animals. Therefore, it is used as an indicator of contamination of human and waste, such as *Escherichia coli* [15-16]. As for rural conservation and agricultural land use surrounding Kuan river and Ngim river which both are tributaries of Yom river and Yom river (Y1 – Y4) TCB and FCB were detected in low amounts, but there was a high amount of NO_3^- (1.68 – 2.24 mg/L), indicating the effects of famers use of chemical fertilizers and surface runoff, consistent with the classification results and the size of use. Land in the upper Yom River Watershed shown with green zones and green - and- white stripes on the map in Figure 1 was found to be 42.29% and 35.97% of the total area 12,952,386.79 square meters (m^3) with land use for conservation and agriculture. It is evident that on more than 50 % of nitrogen fertilizer can be directly used by plants [17]. Much of which is bound to organic matter in the soil and is lost through direct leaching into waterways including the present trends of nitrate pollution of surface water. Therefore, reflect legacies of current and past applications of fertilizers and manures [18-19].

Table 4 Criteria used to evaluate the physical, chemical and biological status of water resources

Status of the upper Yom River Basin, Part 1	Scores
Nature	>3.33
Warning	2.35-3.32
Risky	1.68-2.34
Crisis	<1.68

Table 5 Evaluation of physical water quality in Upper Yom River Basin, Part 1 in Phayao province

Stations	Mean value of physical water quality parameters, n=6							
	Temp (^oC)	Score	Turbidity (NTU)	Score	EC (µS/cm)	Score	TSS (mg/L)	Score
Y1	25	4	12.75	4	161.00	3	23.00	4
Y2	25	4	48.55	3	156.95	3	64.50	4
Y3	25	4	56.01	2	166.15	3	48.50	4
Y4	25	4	51.90	2	169.55	3	55.50	4
Y5	25	4	52.65	2	165.65	3	49.00	4
Y6	25	4	35.80	3	166.50	3	51.50	4
Y7	25	4	40.85	3	170.60	3	40.50	4
Y8	25	4	52.20	2	171.55	3	55.50	4
Standards	Nature[1)]		< 5[1)]		< 1,000[2)]		99[2)]	
Evaluation	**Nature**	**4**	**Warning**	**2.63**	**Warning**	**3**	**Nature**	**4**

Note: [1)] Guidelines for drinking – water quality (WHO, 1996) [11]
[2)] National Storm Water Quality Database (Pitt et al., 2004) [12]

Table 6 Evaluation of chemical water quality in Upper Yom River Basin, Part 1 in Phayao Province

Stations	Mean value of chemical water quality parameters, n=6							
	pH	Score	PO_4^{3-} (mg/L)	Score	NO_3^- (mg/L)	Score	BOD (mg/L)	Score
Y1	7.35	4	0.10	3	1.68	4	1.20	4
Y2	7.40	4	0.25	1	2.24	4	1.95	3
Y3	7.40	4	0.31	1	1.68	4	1.05	4
Y4	7.50	4	0.29	1	2.24	4	1.00	4
Y5	8.05	4	0.46	1	1.96	4	1.35	4
Y6	7.45	4	0.43	1	1.68	4	1.05	4
Y7	7.45	4	0.43	1	1.40	4	1.20	4
Y8	7.45	4	0.54	1	1.68	4	1.10	4
Standards	5 – 9[1)]		< 0.1[2)]		< 5[1)]		2 – 4[1)]	
Evaluation	**Nature**	**4**	**Crisis**	**1.25**	**Nature**	**4**	**Nature**	**3.85**

Note: [1)] Water quality standards for surface water source types 3 and 4 [13]
[2)] Integrated Risk Information System (US.EPA, 1999) [14]

Table 7 Evaluation of biological water quality in Upper Yom River Basin, Part 1 in Phayao Province

Stations	**Mean value of biological water quality parameters, n=6**			
	TCB (MPN/100 mL)	**Score**	**FCB (MPN/100 mL)**	**Score**
Y1	4,000	3	1,325	2
Y2	3,200	3	1,565	2
Y3	2,650	3	1,525	2
Y4	3,310	3	1,715	1
Y5	2,905	3	2,600	1
Y6	4,822	3	1,850	1
Y7	7,800	2	4,500	1
Y8	6,575	2	3,600	1
Standards	20,000[1)]		< 4,000[1)]	
Evaluation	**Warning**	**2.75**	**Crisis**	**1.38**

Note: [1)] Water quality standards for surface water sources types 3 and 4 [13]

Results of assessment of the overall status of the upper Yom watershed are at the warning level with an average score of 2.92 showing that the water quality has begun to deteriorate from its original condition, and it requires surveillance and monitoring of the cause of problem. This is because the water quality index -values are in Warning to Crisis conditions including EC, TCB, Turbidity, FCB and PO_4^{3-} with average scores of 3.00, 2.63, 2.63, 1.38 and 1.25 respectively because the mentioned quality index indicates the agricultural land use and dense residential areas as well as the topography is a high-land with steep slopes and degraded forests, thus affecting the erosion of the soil surface. Sediment in water sources and landslides occurred in the upper Yom Watershed [20].

Conclusion

Assessment of surface water quality in the upper Yom Watershed from land use is at the Warning Level and EC, TCB, Turbidity, FCB and PO43- indices should be monitored periodically and at the specific points. This is the result of land use in agriculture and rural conservation surrounding Yom Watershed and Ngim river which is the tributary of Yom River including the very dense residential areas shows that water quality analysis according to land use pattern will reveal the status of water resources. Water quality index and precision in managing water resources to ensure water and sanitation are sustainably managed and available to all in line with the UN-SDGs.

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Climate Change Mitigation in the Waste Sector: Policies and Measures in Different Countries and the Way Forward for Thailand

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Abstract

This study performed a non-systematic review of climate change mitigation policies in the waste sector across nine selected countries (Thailand, the UK, Germany, Belgium, France, Denmark, Indonesia, China, and Japan). The review aimed to examine the existing policies and measures, identify potential areas of improvement in Thailand's waste sector compared to the selected countries and propose levers of transformation of the policy recommendations for Thailand. Based on the review of waste management policies and measures in nine countries, twelve policies have been implemented in other countries but are not mentioned in Thailand’s reviewed documents. Some of the significant policies and measures identified as potential areas of improvement in Thailand’s waste sector related policies and measures include introducing waste taxation, implementing the Internet of Things (IoT) and Extended Producer Responsibility (EPR), and promoting waste electrical and electronic equipment (WEEE) recycling focusing on solar panel wastes. Recommendations have been provided through the designation of the levers of transformation (governance, economy and finance, individual and collective action, and science and technology). The findings provide valuable insights into strengthening the climate change mitigation efforts specific to the waste sector in Thailand by aligning with international practices. By identifying the areas of improvement and potential policy recommendations analyzed through the lenses of the levers of transformation, Thailand can optimize its waste management strategies, reduce greenhouse gas emissions, and contribute to a sustainable future.

Keywords : Climate change mitigation; Levers of transformation; Non-systematic review; Policy recommendation; Waste sector

Introduction

The waste sector is one of the major contributors to greenhouse gas emissions globally, including Thailand [1]. The total greenhouse gas (GHG) emission of Thailand in 2018 was 372,648.77 $GgCO_2$-eq and the waste sector contributed 4.5% of the emissions (16,703.68 $GgCO_2$-eq) [2]. The government of Thailand along with other countries worldwide is being urged to establish effective policies and actions in a variety of sectors including waste to mitigate climate change [1-3]. Efforts made for efficient waste management can substantially help in lessening climate change problems. The waste management sector of Thailand currently faces challenges due to the rapid waste generation with population growth and the subsequent improper disposal, despite governmental initiatives like the National 3R Strategic Plan and the Solid Waste Management Master Plan [18]. This highlights a critical gap between policy and implementation. Hence, the issue of waste management in Thailand is centered on establishing sustainable consumption and production practices while effectively addressing problems related to rapid waste generation, inadequate infrastructure for waste collection and disposal leading to environmental pollution and health impacts, and proper implementation of regulations and policies to minimize waste generation, promote waste segregation, recycling and proper waste treatment [19]. Aligning with Sustainable Development Goal 12 (SDG12), a comprehensive review of the policies related to the waste management sector is necessary [19]. This study aims to review and compare the available waste sector-related climate change mitigation policies and measures in Thailand and other countries that vary in socioeconomic context, cultural background, waste management practices, and governmental construct. This approach will be beneficial in identifying the successful strategies and potential policy gaps in the waste sector of Thailand when compared with other countries. By focusing on the areas where Thailand lags, valuable insights can be obtained by developing policy recommendations to enhance the country's climate change mitigation efforts in the waste sector. Overall, this study aims to contribute to the global understanding of climate change mitigation policies in the waste sector and provide practical insights to support Thailand's efforts in achieving low carbon sustainable waste management practices.

Methodology

The climate change mitigation policies and measures in the waste sector of nine countries, namely Thailand, the UK, Germany, Belgium, France, Denmark, Indonesia, China, and Japan have been reviewed and compared in this study. The countries were selected based on the Environmental Performance Index (EPI) and the SDG Index rankings [20, 21]. The EPI ranks countries based on their environmental performance while the SDG Index ranks countries based on their progress towards achieving SDG 12. The eight selected countries entail wide variations in rankings for both indices, facilitating a comprehensive analysis (**Table 1**). Developed countries that rank high (Germany, the UK, France, and Denmark) provide insights on the optimum policies for waste management. Developed or developing countries that rank lower (China, Japan, Thailand, and Indonesia) provides insights on the potential strategies of waste management. The inclusion of diverse countries globally enables a comprehensive analysis of waste management policies and measures across various socioeconomic, cultural and governmental contexts. A non-systematic (purposive) review involves selecting and reviewing relevant literature based on predefined objectives to address specific research questions [16]. A non-systematic (purposive) review of available reports on climate change-related policies was conducted, focusing on the waste sector. All climate change mitigation policies and measures specific to the waste sector were compiled and identified from governmentally published official policy documents, reports, or other relevant literature sources, including (but not limited to) national climate change long-term strategies and national adaptation plans. The policies and measures were grouped into the specific waste sector and compared between the countries. This comparative analysis served as the basis for identifying the strengths and weaknesses in Thailand's waste sector policies and measures when compared to other countries. The procedures helped in providing specific policy recommendations and identifying their levers of transformation as key drivers in achieving sustainable waste management in Thailand.

Table 1 Environmental and Sustainable Development Performance Rankings of Selected Countries

Country	EPI [20]	Rank	SDG Index [21]	Rank
Thailand	28.5	100	74.74	43
UK	62.6	26	81.65	11
Germany	69	11	83.36	4
Belgium	68	14	79.46	19
France	63.8	21	82.05	6
Denmark	68.3	13	85.68	3
Indonesia	29.5	96	70.16	75
China	28.6	98	72.01	63
Japan	52.8	47	79.41	21

Results and Discussion

1. Review of country-specific policies and measures

The waste sector-related policies and measures in the selected countries have been discussed. Thailand has attempted to address the problem of waste management by developing national management frameworks, such as the National Solid Waste Management Master Plan (2022-2027) and the Roadmap on Plastic Waste Management (2018-2030) [1]. The Zero Industry Waste to Landfill policy and the "Green Industry Mark" for environmentally friendly processes were adopted to reduce industrial waste generation [2, 3]. Thailand will continue to manage the waste and wastewater sector and reduce its GHG emissions by reducing waste generation, increasing recycling, increasing biogas production from industrial wastewater, and improving efficiency in industrial and municipal wastewater management. Japan aims to ensure decarbonization in local regions through 1) "reuse" of used products to become a common practice instead of discarding them as waste; 2) electricity, heat, CO_2, biogases, etc., derived from waste treatment and sewerage systems in the local regions; and 3) driving efficiency improved by utilizing IoT (Internet of Things) technology in waste treatment facilities [4, 5]. In Indonesia, the long-term pathway considers both historical trends and projections of future waste management activities, particularly methane gas (CH_4) from the waste treatment of municipal solid waste (MSW), domestic wastewater, and industrial waste [7]. In China, strategic priorities and policy orientations aim to establish low GHG emissions in MSW, agricultural wastes, and industrial wastes [8]. In the United Kingdom, the Resources and Waste Strategy (RWS) 2018 specifies that the country will transition to a more circular economy, including key reforms to enable more efficient waste management, reduce the amount of waste created by society, and ensure more efficient resource use. The draft Waste Prevention Programme for England (WPP) sets out the overall approach to improving resource efficiency across all key sectors and announces the government's intention to consult on the introduction of extended producer responsibility across a range of sectors. The Industrial Decarbonization Strategy outlines ambitious targets for resource efficiency measures across the industry [9]. Belgium plans a gradual but complete phase-out (in Flanders and Brussels), or at least a very large reduction in landfilling or incineration of waste by 2050, eliminating virtually all GHG emissions [10]. Denmark's Climate Plan for a green waste sector and circular economy includes a vision for a carbon-neutral waste sector by 2030 and for eliminating the incineration of 80% of Denmark's plastic waste by 2030, as well as for turning the waste curve toward less waste, less wastage, and more recycling. There are several initiatives for better and more rational waste separation, more recycling, and adjustment of incineration capacity [11, 12]. France has a National Waste Management Plan to implement the European waste management hierarchy: prevention, reuse, recycling, recovery, and disposal. The circular economy roadmap (2017 and 2018), followed by the anti-waste law for a circular economy (2020), focuses on eliminating the different forms of waste, strengthening consumer information, mobilizing industry to change production methods, improving waste collection, and sorting, and eliminating illegal dumping [13, 14]. To extend the useful life of products and avoid waste, the German government will consider measures and specific instruments for implementation.

2. Comparison of policies and measures in the waste sector

A comprehensive overview of the availability of different waste stream-specific policies and measures in the reviewed literature and their implementation status have been compiled and compared between the nine countries in **Table 2.** The purposive review process involved identifying government-issued reports on national climate change strategies and plans. Subsequently, the identified documents were reviewed to extract information regarding policies and measures related to the waste sector within the context of climate change mitigation. The results highlight that the selected reports for review on climate change mitigation strategies in this study may not be extensively detailed regarding the waste sector-related policies and measures. The information available on waste sector-specific policies and measures varies across the selected countries due to factors such as varying national priorities, the waste sector is already performing well or their contribution to the overall climate change impact might be less significant. The differences in the reporting practices can also influence the level of detail provided for the waste sector in different country's climate change-related policy reports. Hence, the unavailability of specific waste sector-related policies for specific countries (in **Tables 2** and **3**), cannot be interpreted as an absolute confirmation that the specific policy does not exist within that country, but it indicates that the policy was not definitively mentioned in the reviewed climate change mitigation reports.

3. Areas of improvement in the policies and measures of Thailand in comparison with other countries

The waste sector-specific policy and measures have been compiled and compared in terms of the implementation status in Thailand (**Table 3**). A broad perspective of the status of different waste sector-specific policies has been provided in **Table 2** and **Table 3** building upon this foundation to focus on individual policies and measures, highlighting Thailand's status of policy implementation. Based on the review of waste management policies and measures in nine countries, including Thailand, a total of twenty-four policies and measures were compiled. Three policies have already been implemented in Thailand and six policies have been proposed for implementation in Thailand. Three policies are not applicable or practical to be implemented in the context of Thailand. Currently, twelve policies have been implemented in other countries but are not mentioned in Thailand's reviewed documents, indicating the potential areas of improvement in existing waste sector-related policies and measures in Thailand.

4. Levers of transformation and policy recommendations for Thailand

Based on the review of policies and measures related to the waste sector in nine countries, twelve areas of improvement were identified in Thailand's current policies and measures compared to other countries (see **Table 3**). Some of the significant policies and measures identified as current areas of improvement in Thailand's waste sector related policies and measures include adopting renewable energy generation by utilizing waste; investing IoT in the waste sector and recycling technologies; collecting recyclable waste; disposing biodegradable waste to landfills; introducing producers for responsibility of plastic wastes; adding tax on wastes; promoting increased share of recycled plastic to replace virgin material; decarbonizing industrial wastes; enhancing waste-to-energy initiatives; and strengthening regulatory framework GHG emission reduction in waste sector. All twelve policies and measures are recommended to enhance the waste sector-related policies of Thailand. Amongst the twelve policies and measures, four have been discussed in detail considering the economic feasibility in the context of Thailand and to expedite the progress towards achieving the 2030 target for the national waste management goals. This prioritization ensures the proposed measures are impactful, financially viable and implementable in the current timeframe (**Table 4**).

Measure 1: Introducing waste taxation for waste minimization

Introducing waste taxation to reduce waste generation and promote recycling amongst both producers and consumers by informing them about the environmental and economic significance of waste. Utilizing the revenue generated from the tax to support sustainable waste management initiatives, including recycling infrastructure development, waste-to-energy projects, and research on innovative waste management technologies. The scheme should ensure equitable implementation by targeting specific groups responsible such as the large-scale producers and high-waste consumers through a differentiated tax structure, without placing an economic burden on low-income groups.

Measure 2: Implementing the Internet of Things (IoT) in the waste sector

Implementing the benefits of IoT technology by digitizing Thailand's database and supporting data-driven decision-making to improve waste management systems, improve data collection and monitoring, support research, improve transparency and accountability, and improve operational efficiency by optimizing the allocation of resources for waste collection, workforces, equipment, recycling, data analysis, etc.

Measure 3: Implementing Extended Producer Responsibility (EPR) for wastes

Establishing regulations and mechanisms to hold producers accountable for the entire life cycle of products, including collection, recycling, replacing virgin material manufacturing, and safe disposal.

Measure 4: Promoting waste electrical and electronic equipment (WEEE) recycling focusing on solar panel wastes

Implementing efficient methods for the collection, recycling, and end-of-life disposal of WEEE responsibly, including solar panel wastes for effective management of hazardous materials, minimization of environmental pollution, and maximization of resource recovery for new economic opportunities for recycling and material recovery-related sectors

These recommendations have been deduced as potential advancements in the waste sector-related policies and measures for Thailand through the designation of the levers of transformation (governance, economy and finance, individual and collective action, and science and technology) (**Table 3**). The lever of transformation is a policy tool that can be used for many purposes, including understanding the policy landscape and identifying essential drivers for driving policies [17]. The recommendations are intended to help Thailand to improve its waste management policies and measures in a significant way.

5. Limitations and scope for future improvement

The purposive review in this study facilitated a focused analysis by allowing the selection of literature based on the researcher's judgement focusing on keywords related to climate change mitigation in the waste sector. This approach limits the analysis by introducing potential biases. Future studies should focus on specifying clear criteria for selecting literature that is comprehensive to mitigate such biases. While the nine countries selected in this review offer a comparative perspective, they may not provide a diverse and comprehensive global understanding of waste management policies and measures. The study relied on governmentally published official reports on climate change mitigation strategies with a focus on the waste sector which ensures reliability, nonetheless, it limits the scope of this review due to the exclusion of the full spectrum of data available on waste management policies. The specific focus on climate change mitigation policies and measures within the waste sector might have resulted in excluding other relevant waste management-related policies that are not explicitly mentioned in the context of climate change. Further, variations in national priorities and reporting practices can influence the level of detail provided in different country's climate change-related policy reports. The categorization of policies and measures in **Table 2** provides a general overview and future research can focus on reviewing the details of policy implementation such as specific provisions, level of government responsibility and progress or effectiveness of the policy. Further, GHG emission profiles of various waste sectors have not been explored in this study, which limits the potential to directly compare the status of waste sector of Thailand with other countries. Including such comprehensive analysis of waste sector-specific emission will be a valuable addition for future research efforts to support evaluating policy effectiveness. Future studies could benefit from adopting a systematic approach with extensive data collection processes, detailing the effectiveness of various policies and measures. Despite these limitations, this review offers a foundation for identifying areas of improvement in Thailand's waste management strategies.

Table 2 Status of different waste sectors compared between different countries and Thailand

Waste Sector / Country	Thailand	Japan	Indonesia	China	United Kingdom	Belgium	Denmark	France	Germany
Food Waste	◎	◎	✗	✗	◎	✗	✗	✗	✗
Plastic Waste	✓ ◎	★	✗	✗	✓	✗	◎	◎	✗
Landfill Waste	★ ◎	✗	✗	✗	✗	◎	◎	✓	✓ ◎
Marine Waste	◎	✗	✗	✗	✗	✗	✗	✗	✗
Agricultural Waste	★ ✓	◎	✗	✗	✗	✗	✗	✗	✗
Industrial Waste	✗	✗	◎	◎	★	✗	✗	✗	✗
Municipal Solid Waste (MSW)	✗	✗	✓ ◎	◎	★ ◎	✗	✗	◎	✗
Wastewater	◎	◎	◎	✗	◎	✗	◎	✗	✗
Waste Electrical and Electronic Equipment (WEEE)	✗	◎	✗	✗	✗	✗	✗	✗	✗

★ Policies and measures have been enacted.

✓ Policies and measures have been implemented/executed.

◎ Policies and measures have been proposed with targets for the future.

✗ Policies and measures are unavailable in reviewed literature.

Table 3 Status of waste sector-related policy/measures implementation

No.	Policy/Measure	Implementing countries	Thailand Status
1	National Plan for waste management	Indonesia and France	Implemented (National Solid Waste Management Master Plan (2016-2021)) [1,2]
2	Plan for plastic waste management	Japan, United Kingdom, and Denmark	Implemented (Roadmap on Plastic Waste Management (2018-2030)) [1,2]
3	Biofuel from biowastes	China	Implemented (Alternative Energy Development Plan (2018-2037)) [2,3]
4	Promotion of circular economy	China, United Kingdom, Denmark, France, and Germany	Proposed (BCG Model) [1,2]
5	3R Principle	Japan, Indonesia, China, United Kingdom, Denmark, France, and Germany	Proposed (Draft National Waste Management Action Plan (2022-2027)) [1,3]
6	Food waste reduction/ sustainable consumption	Japan and United Kingdom	Proposed (reduce food waste by 50% in 2030) [2,3]
7	Zero waste to Landfill	United Kingdom, Belgium, and France	Proposed (Zero Industry Waste to Landfill policy) [2,3]
8	Waste to Energy	Indonesia and Japan	Proposed (NDC Sectoral Action Plan for the Waste Sector 2021 – 2030) [1,2]
9	Public Private Partnership	Japan and Denmark	Proposed (NDC Sectoral Action Plan for the Waste Sector 2021 – 2030) [1,2]
10	Anti-waste Law for Circular economy	France	Not applicable for Thailand
11	Sewerage system installation (replacing septic tank)	Denmark	Not applicable for Thailand
12	Elimination of incineration of waste	Belgium, Denmark, and France	Not applicable for Thailand
13	IoT in waste sector	Japan	Identified as potential area of improvement
14	Investment in recycling technology	Japan and Germany	Identified as potential area of improvement
15	Elimination of biodegradable MSW to Landfill	United Kingdom, France, and Germany	Identified as potential area of improvement
16	Renewable energy technology in wastewater	Japan, Indonesia, and United Kingdom	Identified as potential area of improvement
17	WEEE recycling	Japan	Identified as potential area of improvement
18	Increase septic tank for biogas recovery (Decentralized sewage treatment)	Indonesia and China	Identified as potential area of improvement
19	Extended producers' responsibility (EPR) for plastic wastes	United Kingdom, Denmark, and France	Identified as potential area of improvement
20	Plastic Packaging Tax	United Kingdom	Identified as potential area of improvement
21	Landfilling waste Tax	United Kingdom, Denmark, and France	Identified as potential area of improvement
22	Climate Plan for green waste sector	Denmark	Identified as potential area of improvement
23	Increase share of recycled plastics in manufacturing	United Kingdom and Denmark	Identified as potential area of improvement
24	Industrial Decarbonization Strategy	United Kingdom and China	Identified as potential area of improvement

Table 4 Policy recommendations for Thailand for the respective levers of transformation

Lever of transformation	**Measure 1: Introducing waste taxation for waste minimization**	**Measure 2: Implementing the Internet of Things (IoT) in the waste sector**	**Measure 3: Implementing Extended Producer Responsibility (EPR) for wastes**	**Measure 4: Promoting WEEE recycling focusing on solar panel wastes**
Governance	Establish a national waste management plan that is routinely and rigorously monitored by an authority specifically responsible for the effective enforcement of the waste management measures.	Establish independent monitoring authorities to oversight adherence to regulatory guidelines and adequate utilization of resources of IoT systems. Establish an integrated multi-stakeholder collaborative approach in policy development and knowledge sharing fostering transparency and accountability.	Set standards that require producers to take responsibility for the proper collection and recycling at the end of life of their wastes.	Develop and enforce regulations and standards for WEEE stipulating the accepted treatment methods, licensing of facilities and penalties for non-compliance or environmentally unsafe dumping practices.
Economy and finance	Introduce tiered tax system on different types and amounts of wastes to curb waste generation by inculcating responsibility for waste minimization and generate revenue to support recycling initiatives.	Public-Private Partnerships (PPPs) via cost sharing models where public sector collaborates with private sector as an optimized route for cost saving. Public sector provides the infrastructure while private sector invests and maintains the IoT technology.	Introduce market-based incentives to support the EPR scheme such deposit-refund approach where the deposit paid for the purchase of specific products will be refunded after returning for proper recycling.	Establish recycling funds financially supported by businesses producing WEEE. The revenue collected via waste tax can also be allocated to subsidize establishing and operating the WEEE recycling facilities.
Individual and collective action	Educate, encourage, and facilitate the public about individual responsibility for reducing waste or separating different wastes before discarding via public awareness campaigns.	Develop a transparent platform to update the public and private sectors on their waste collection and recycling via a tracking app or website.	Develop a "one stop service hub" where all producers, waste collectors, and recyclers can be connected easily and transparently.	Form a network for WEEE recycling centers that are community based and are staffed with volunteers who also provide training for WEEE recycling.
Science and technology	Invest in research and development of new technologies tailored to treat specific types of wastes and recover resources from wastes.	Invest in research and development in IoT to track the waste collection, monitor the waste composition and provide real time information to waste managers to improve efficiency in waste sector.	Invest in research and development in EPR schemes that are tailored to address the requirements of that are specific to the different industries and the types of waste they produce.	Invest in research and development in recycling technologies that are environmentally sound and economically viable, considering that it is expensive to recycle WEE and require special handling as they are hazardous.

Conclusions

Climate change mitigation related policies and measures specific to the waste sector were reviewed for Thailand and other countries (the UK, Germany, Belgium, France, Denmark, Indonesia, China, and Japan). The comparative analysis revealed that Thailand has made progress in terms of climate change mitigation policies in the waste sector, but there are still areas that require attention and improvement. To address these potential areas of improvement and foster transformation in the waste sector, the recommendations have been categorized into four levers of transformation (governance; science and technology; economy and finance; and individual and collective action). These levers have the potential to advance sustainable waste management practices in Thailand, reduce greenhouse gas emissions, and promote circular economy principles in the waste sector. Future studies are essential to explore the detailed, specific mechanisms of the described lever (of each policy recommendation) to realize the full potential of the policy recommendations. The recommendations proposed in this study are intended to assist policymakers in formulating effective policies and strategies for the waste sector in Thailand. By implementing these recommendations, Thailand can reinforce climate change mitigation efforts, improve waste management practices, and contribute to the global transition towards low-carbon and sustainable waste management.

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Removal of Dichloroacetonitrile in Synthetic and Tap Water by Napier grass-derived Adsorbent

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Abstract

The objectives of this study are to investigate the characteristics of Napier grass-derived adsorbent and its efficiency on DCAN removal in synthetic water and tap water. Napier grass is one of the materials that contains a high amount of cellulose content. Thus, it can be utilized as an alternative and potential sustainable resource of raw material to produce biosorbent. Napier grass-derived adsorbent was produced by carbonized at 600 °C under Liquefied Petroleum Gas (LPG) for 1 hour. The characteristics of Napier grass-derived adsorbent were investigated by using the Brunauer Emmett-Teller (BET) method and the surface charges by using Point of Zero Charge (PZC) method. The results showed that BET surface area was 182.53 m^2/g, average pore diameter was 2.9579 nm., and PZC was approximately 7 both in synthetic water and tap water. Napier grass-derived adsorbent was proved to provide high efficiency to remove DCAN from water source. The removal efficiency was increased with increasing adsorbent. The optimal dosage of Napier grass-derived adsorbent was 2.0 g/L both in synthetic water and tap water with more than 90% removal efficiency. Adsorption kinetics were conducted, it was found that the adsorption of DCAN by using Napier grass-derived adsorbent was fitted to pseudo-second order which can be indicated that the mechanism of adsorption was chemisorption. The adsorption was reaching equilibrium after 50 minutes both in synthetic water and tap water. In addition, the adsorption isotherm was conducted and found that physical adsorption was the major adsorption mechanism of DCAN in Napier grass-derived adsorbent.

Keywords : adsorption; dichloroacetonitriles; haloacetronitrile; low-cost adsorbent; napier grass

Introduction

Haloacetonitriles (HANs) is the regulated disinfection by-product (DBPs) which are classified as nitrogenous disinfection by-products [1]. It has been reported as a stronger cytotoxicity and genetic toxicity [2]. Dichloroacetonitrile (DCAN) is a type of haloacetonitriles (HANs) which mostly detected in tap water [3]. Tap water in Bangkok has been found to contain DCAN in concentrations of 2.5 to 27 μg/L [4]. In addition, it was found that the water distribution networks of Khon Kaen Municipality have been detected HANs (DCAN, TCAN and DBAN) up to 30 μg/L [5].

DCAN is a by-product of the chlorination of humic substances, algae and amino acids contained in drinking water and pulp bleaching processes. It is formed during the chlorination process of water and wastewater treatment with the occurrence of humic substance as a precursor. DCAN affects animal, aquatic, and plant life; and conformance with environmental and public health regulations [6]. So, the WHO guideline value for DCAN in drinking water is set at 0.02 mg/L or 20 μg/L. Therefore, it is crucial to control DCAN formation in a water treatment system. Various physical or chemical methods were used to remove DCAN from aqueous solution to reach a standard concentration such as precipitation, photocatalysis and adsorption [7-9]. Adsorption technique is deserving as promising technique to remove DCAN from water due to its low consumption of energy, simple operation, high efficiency, low cost as well as the wide suitability for purified water [10].

Activated carbon is a well-known and efficient adsorbent that is commonly used in the environmental aspects. Nowadays, low-cost materials are increasingly utilized as low-cost adsorbent due to the low cost and related to the waste reduction issue. Several low-cost materials were utilized as low-cost adsorbent such as pig bone, cotton, canvas fabric, corn etc.

In Thailand, Napier grass has been promoted for planting to be use as alternative animal feeding. It was attended because of its fast growth without much nutrients supply, good disease resistance, adaptability, high production yield and easy propagation. Napier grass is also considered as a cheap cellulosic resource [11]. Importantly, it contains a high amount of cellulose content about 35–50% [12]. Thus, this material has been the principal reason for supplement as an alternative and potential sustainable resource of raw material to produce biosorbent. However, the condition for producing biosorbent from Napier grass is not well determined. In addition, the adsorption efficiency and adsorption mechanism of Napier grass adsorbent on DBPs rarely conducted. So, the Napier grass was utilized as raw material for producing Napier grass-derived adsorbent. Thus, the purposes of this research are to investigate the characteristics of Napier grass-derived adsorbent and its efficiency on DCAN removal.

Methodology

Synthesis of the Napier grass-derived adsorbent

Dry Napier grass was used as raw materials for preparation of Napier grass-derived adsorbent. Napier grass was carbonized at 600 °C under Liquefied Petroleum Gas (LPG) for 1 hour with the pilot furnace which fed raw Napier grass 1 kg. The details of pilot furnace was proposed by the study of Sriboonnak (2019) [13]. The size of Napier grass-derived adsorbent was sieved by 60-100 mesh sieve size to obtains the particle size of Napier grass char in the range of 100-250 µm.

Characterization of Napier grass-derived adsorbent

The characteristics of Napier grass-derived adsorbent were analyzed. The specific surface area was determined by using The Brunauer Emmett-Teller (BET) method with the nitrogen adsorption isotherm at temperature 77 kelvin using the Automatic Surface Analyzer Instrument (Quanta Chrome, model autosorb 1) and the surface charges were investigated by using Point of zero charge (PZC) method.

The PZC experiment was conducted with the initial solution from synthetic water and tap water. The pH of initial solution was adjusted to a range of 1 – 14 by using 0.1 and 0.5 M of NaOH and HCl. After that, the Napier grass-derived adsorbent was added into a flask that contained the initial solution. Then, it was shaken at 200 rpm under room temperature for 48 hr and measured pH every 24 hr. Finally, the initial and final pH were plotted together. The result of PZC from synthetic water and tap water was compared.

Removal of DCAN by Napier grass-derived adsorbent

In the DCAN removal experiment, two sources of water sample were used during the experiment including synthetic water and tap water. Synthetic water was prepared by dissolved potassium dihydrogen phosphate and dipotassium hydrogen phosphate in milli-Q water. While tap water was taken from the laboratory room at department of Environmental Engineering, Faculty of Engineering, Chiang Mai university. DCAN was purchased from Sigma-Aldrich®, Laboratory grade.

The DCAN removal experiment was conducted with 100 mL of DCAN solutions at initial concentration 50 µg/L. The prepared solution was added to the volumetric flask containing Napier grass-derived adsorbent in the varied dose of 0.25 to 3.0 g/L. Then, it was shaken at 200 rpm under room temperature for 24 hr. After that, the samples were filtered through a 0.20 µm nylon syringe filter. DCAN concentrations were analyzed by Gas

Chromatography (GC). Then, compared results between synthetic water and tap water.

Adsorption Kinetics

The adsorption kinetics experiment was investigated by using 2.0 g of Napier grass-derived adsorbent in 100 mL of water sample containing 50 μg/L of DCAN. The adsorption kinetic was conducted by shaking at 200 rpm under room temperature for 24 hours. The water samples were collected at various times including 0.5, 1, 3, 5, 10, 20, 30, 40, 50, 60, 180, 360, 720, 900, 1080, and 1440 minutes. The collected water samples were filtered through a 0.20 μm nylon syringe filter and DCAN concentrations were analyzed by Gas Chromatography (GC). Then, compared results between synthetic water and tap water.

The pseudo-first order and pseudo-second order were investigated by plotting graph of a linear equations in Equation 1 and Equation 2, respectively.

$$\log (Q_e - Q_t) = \log Q_e - [(k_1/2.303)*t] \quad (1)$$

$$t/Q_t = [1/(k_2 Q_e^2)] + (t/Q_e) \quad (2)$$

Adsorption Isotherm

The adsorption isotherm experiment was conducted by using 2.0 g of Napier grass-derived adsorbent in 100 mL of water sample. Water sample was varied the DCAN concentration at 25, 50, 75, 100 and 125 ug/L. The adsorption kinetic was conducted by shaking at 200 rpm under room temperature for 50 minutes. The linear and Freundlich isotherm equation are shown in Equation 3 and 4, respectively.

$$1/q_e = 1/q_m + 1/(b q_m C_e) \quad (3)$$

$$q = K_f\, C_e \wedge^{(1/n)} \quad (4)$$

Results and Discussions

Characteristics of Napier grass-derived Adsorbent

BET surface area of Napier grass-derived adsorbent was 182.53 m^2/g and average pore diameter was 2.9579 nm. The results of BET surface area and average pore diameter were compared with the low-cost adsorbent for calico fabric as shown in Table 1.

From the results in Table 1, it was found that the surface area of Napier grass-derived adsorbent was lower than calico fabric-derived adsorbent due to the production of calico fabric-derived adsorbent used higher temperature (880 ^oC) than the production of Napier grass-derived adsorbent (600 ^oC). From the results, it can be confirmed that the production of adsorbent at higher temperatures results in surface area increasing and lower pore diameter. However, production of adsorbent at higher temperatures requires higher operation cost.

The surface charges of Napier grass-derived adsorbent in synthetic water and tap water were studied through point of zero charge (PZC) by varied pH of solution. The results are shown in Figure 1 and Figure 2, respectively.

From the results, it was found that the point at which the total charge is equal to zero was approximately 7 both in synthetic water and tap water. If the pH value in solution was lower than pH value at PZC, the carbon surface has a net positive charge. On the other hand, if the pH value in solution higher than pH value at PZC, the carbon surface has a net negative charge [15].

The DCAN removal efficiency by Napier grass-derived adsorbent

The DCAN removal efficiency by Napier grass-derived adsorbent was investigated under synthetic and tap water. The results are shown in Figure 3 and Figure 4, respectively.

From the obtained results, it was found that DCAN was highly adsorbed by Napier grass-derived adsorbent. The DCAN species can absorb on the adsorbent surface and inside the pore volume [15]. The DCAN removal efficiency was increased with increasing of Napier grass-derived adsorbent dosage both in synthetic water and tap water. The highest DCAN removal efficiency was found at Napier grass-derived adsorbent dosage 3.0 g/L for both synthetic water (100%) and tap water (100%), respectively. When considered the DCAN removal efficiency from Napier grass-derived adsorbent dosage at 2.0 g/L, it found that the removal efficiency was higher than 95% and close to removal efficiency from 3.0 g/L dosage. Therefore, the optimal dosage of Napier grass-derived adsorbent should be 2.0 g/L due to provide higher efficiency and use less adsorbent.

Table 1 The comparison of BET surface area and average pore diameter

Materials	S_{BET}[a] (m^2/g)	pore diameter (nm)
Napier grass-derived Adsorbent	182.53	2.958
Calico fabric-derived Adsorbent[b]	262.51	1.514

[a] The Brunauer-Emmett-Teller (BET) surface area

[b] Yimyam, (2023) [14]

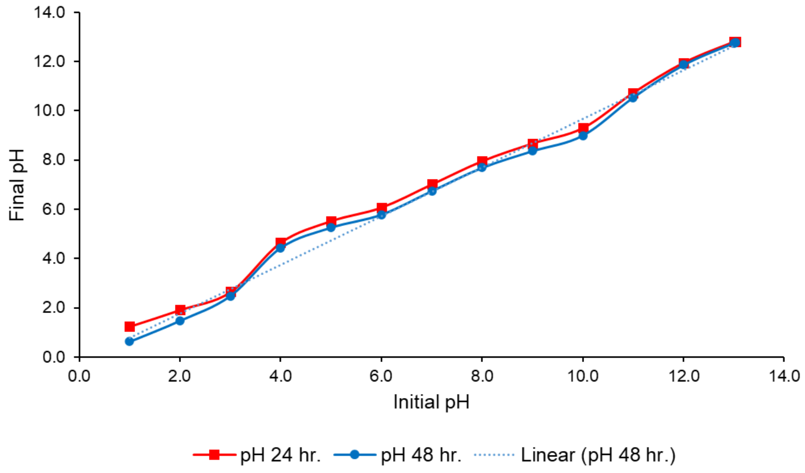


Figure 1 Point of zero charge (PZC) of Napier grass-derived adsorbent in synthetic water

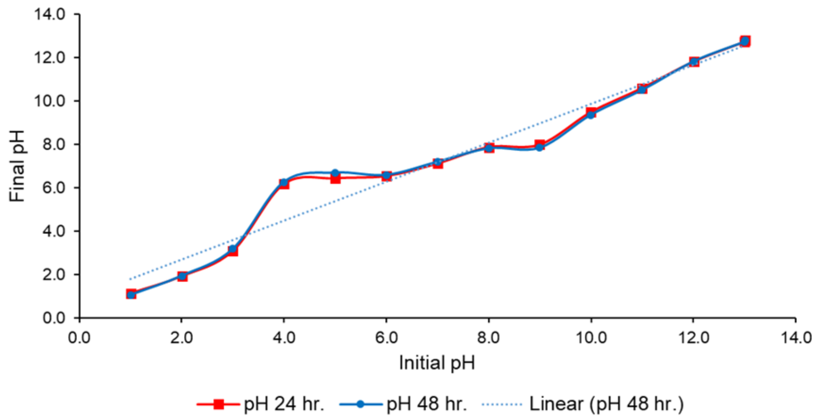


Figure 2 Point of zero charge (PZC) of Napier grass-derived adsorbent in tap water

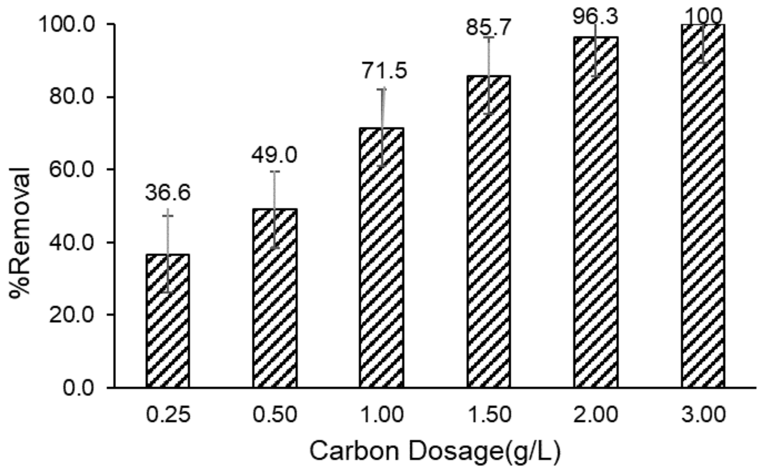


Figure 3 Removal efficiency of DCAN in synthetic water

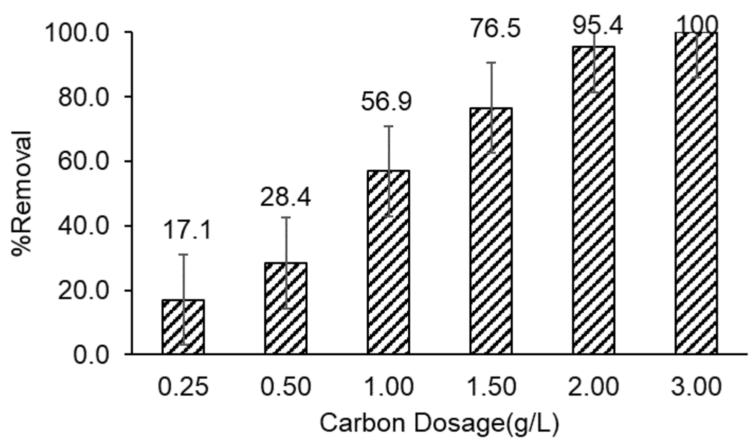


Figure 4 Removal efficiency of DCAN in tap water

When compared the results of synthetic and tap water, the DCAN removal efficiency in tap water was lower than those in synthetic water at the same Napier grass-derived adsorbent dosage. The decrease of removal efficiency might be affected from the presence of organic and inorganic matter in tap water. The organic and inorganic matter presence in tap water can be absorbed by Napier grass-derived adsorbent. Thus, it can reduce the removal efficiency of DCAN.

Kinetic adsorption of Napier grass-derived adsorbent

Kinetic adsorption of DCAN by Napier grass-derived adsorbent in synthetic water and tap water were studied. The kinetic curve for DCAN adsorption on Napier grass-derived adsorbent in synthetic and tap water are shown in Figure 5 and Figure 6, respectively.

The results from adsorption kinetic showed that the adsorption rate was fast in the beginning and then slowed down before reaching equilibrium condition. The adsorption rate was related to the adsorption capacity of adsorbent. The quick adsorption rate in the beginning step might be due to the high number of active sites on the adsorbent surface in the beginning of adsorption experiment [16]. The equilibrium time for DCAN adsorption by Napier grass-derived adsorbent in synthetic water and tap water was 50 minutes. The equilibrium time for DCAN adsorption was the same as DCAN adsorption using adsorbent from calico fabric materials [14]. The quickly of reaching equilibrium related to the molecular surface, it can be stated that the molecular surface of Napier grass-derived adsorbent was the same as adsorbent from calico fabric materials.

The kinetics model was investigated by plotting graphs of linear equations of pseudo-first order and pseudo-second order in Equation 1 and Equation 2, respectively. The plotting of pseudo-first order and pseudo-second order of synthetic water are shown in Figure 7 and Figure 8, respectively.

From the linear plot with the pseudo-first order and pseudo-second order equation is shown in Figure 7, the obtained correlation coefficient (R^2) was 0.9458 and 0.9900, respectively. While the obtained result in Figure 8 showed that the correlation coefficient (R^2) was 0.9195 and 0.9851, respectively. Thus, it can conclude that the adsorption of DCAN by using Napier grass-derived adsorbent was fitted with pseudo-second order both in synthetic and tap water. It can be described that the adsorption mechanism on Napier grass-derived adsorbent is caused by chemical forces (Chemisorption) and depends on the sharing or exchange of electrons [17]. The results were well related to the results of DCAN removal by using adsorbent produced from calico fabric which reported that it was fitted to pseudo-second order model with higher correlation coefficients (R^2 = 0.9890) [14].

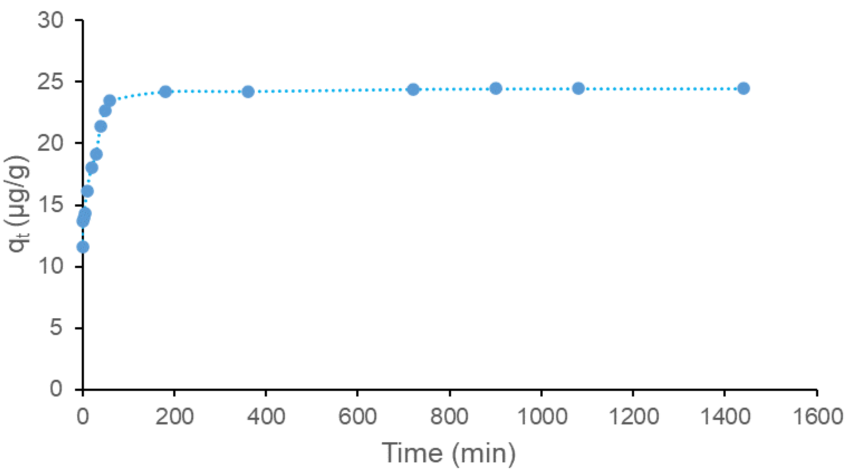


Figure 5 Adsorption kinetic of DCAN on Napier grass-derived adsorbent in synthetic water

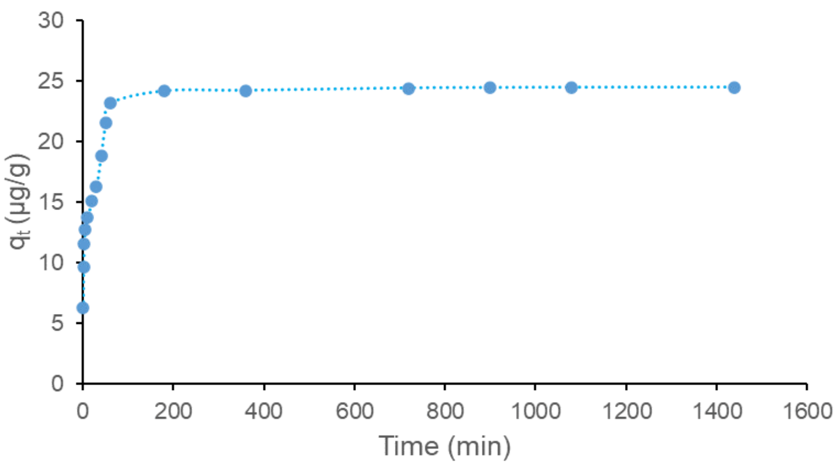


Figure 6 Adsorption kinetic of DCAN on Napier grass-derived adsorbent in tap water

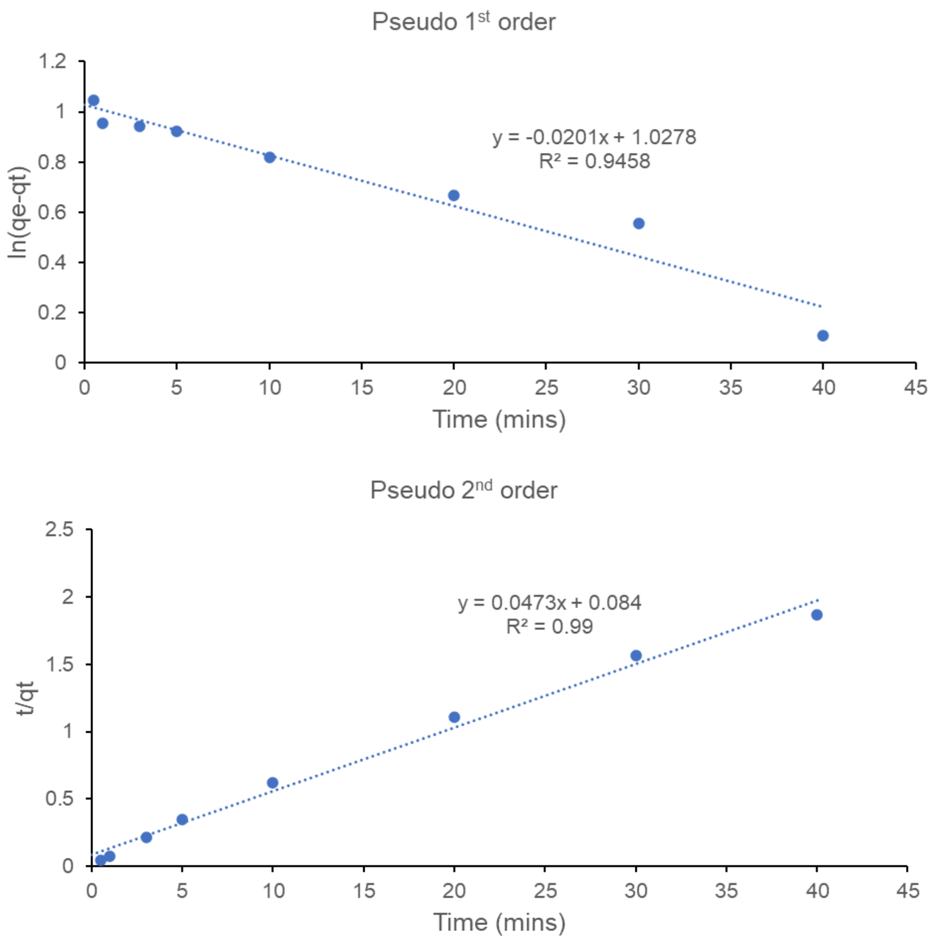


Figure 7 Linear equations of pseudo-first order and pseudo-second order of Napier grass-derived adsorbent in synthetic water

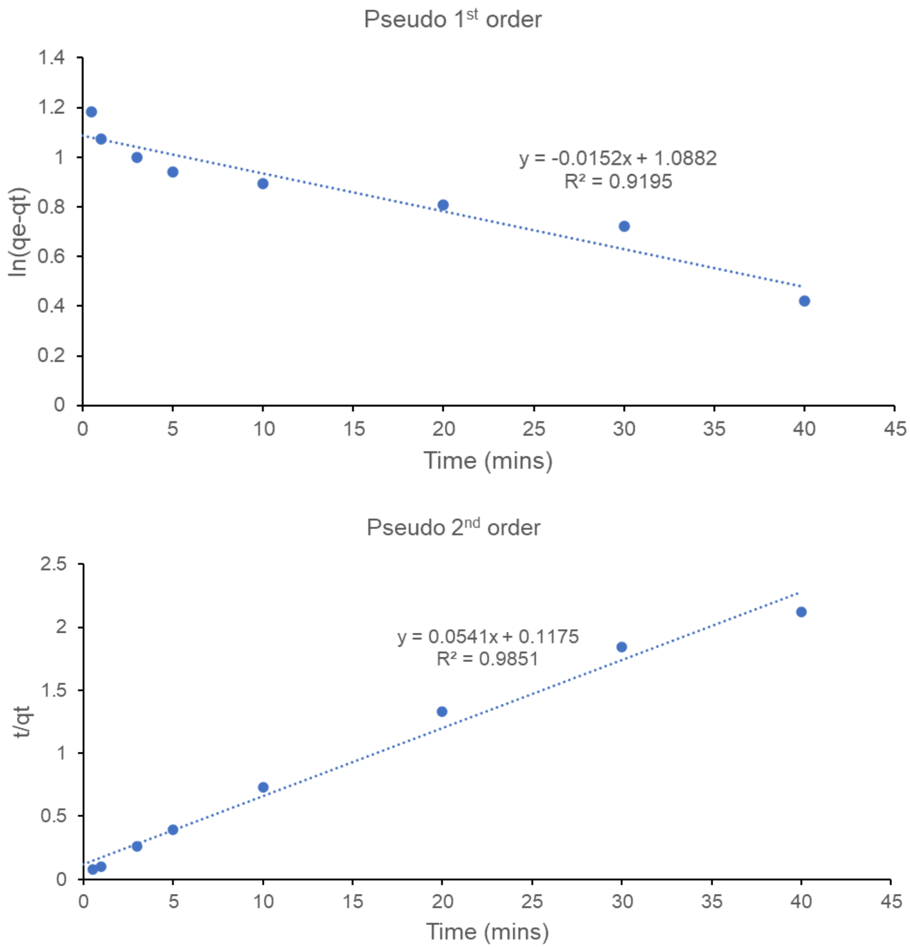


Figure 8 Linear equations of pseudo-first order and pseudo-second order of Napier grass-derived adsorbent in tap water

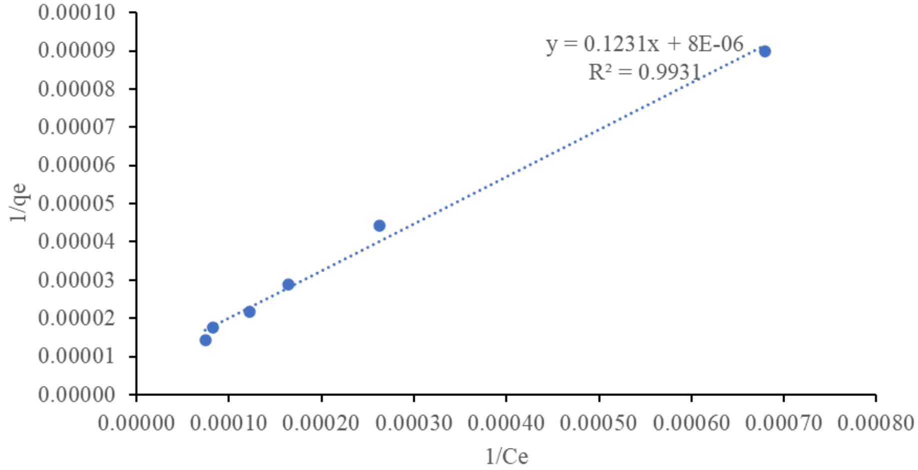
Adsorption isotherm of Napier grass-derived adsorbent

Adsorption isotherm of DCAN by Napier grass-derived adsorbent in synthetic water and tap water were studied. The linear isotherm curve and freundlich isotherm curve for DCAN adsorption on Napier grass-derived adsorbent in synthetic and tap water are shown in Figure 9 and Figure 10, respectively.

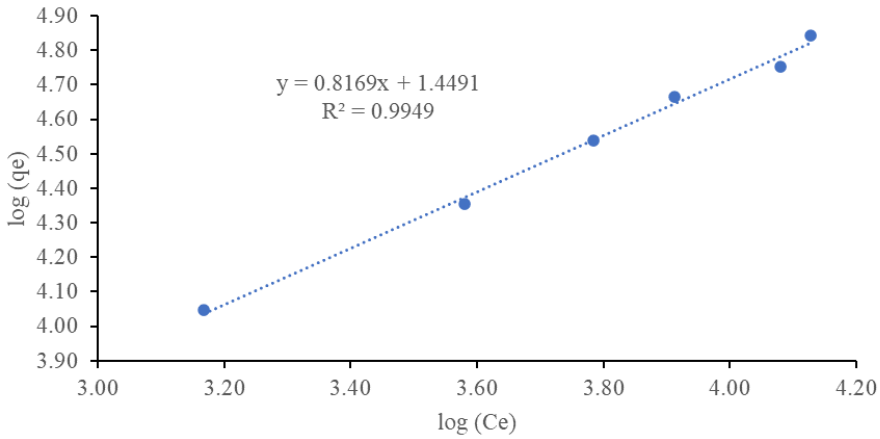
From the results of linear adsorption isotherm, the amount of DCAN adsorbed on adsorbent in synthesis water and tap water were 129.87 and 178.57 ug/g, respectively. On the other hand, the results of freundlich isotherm showed that the Kf constant of DCAN adsorbed on adsorbent in synthesis water and tap water were 7.94 and 2.32 ug/g, respectively.

When comparing the R^2 value of linear and freundlich isotherm it was found that the R^2 of freundlich isotherm was higher that R^2 of linear isotherm in synthesis water. It can be indicated that the adsorption isotherm was related to freundlich isotherm. Thus, the adsorption mechanism of DCAN in synthesis water was physical adsorption and adsorb with multiple layers on adsorbent.

Interestingly, the adsorption isotherm of DCAN in tap water was linear isotherm based on the higher R^2 values obtained. It can be indicated that DCAN was absorbed on adsorbent surface with only one layer. It might be due to the contaminant particle in tap water that need to conduct further research to clarify this assumption.

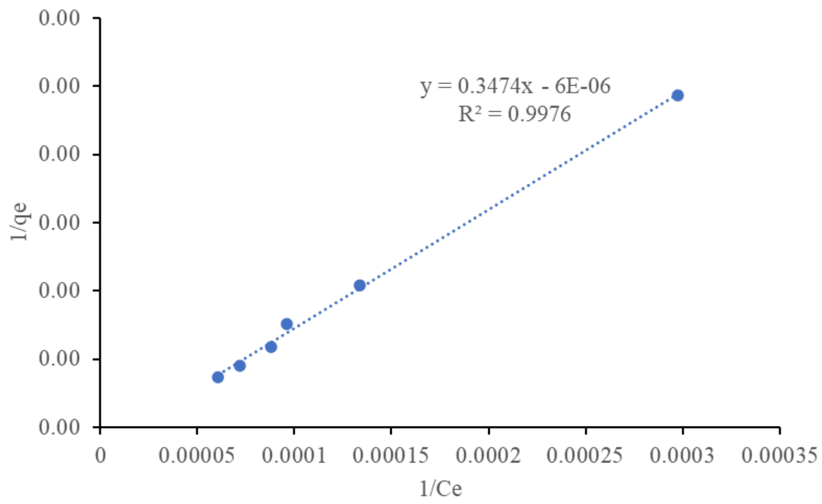


(a)

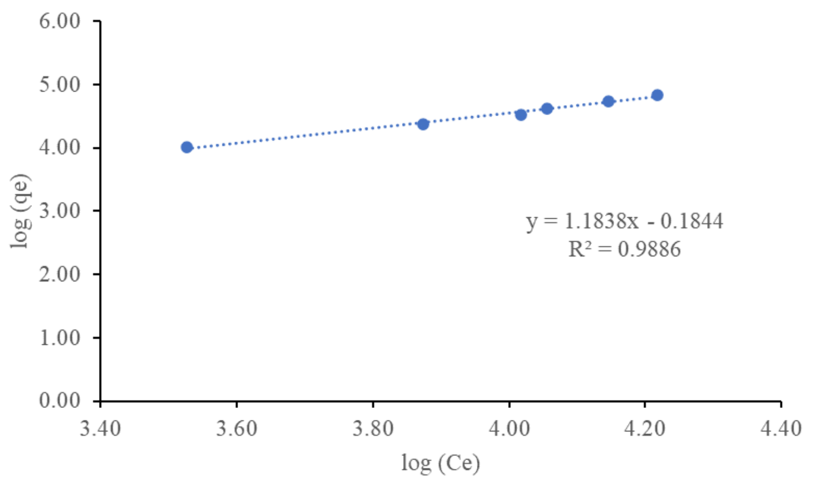


(b)

Figure 9 (a) linear isotherm curve and (b) freundlich isotherm curve for DCAN adsorption on Napier grass-derived adsorbent in synthetic



(a)



(b)

Figure 10 (a) linear isotherm curve and (b) freundlich isotherm curve for DCAN adsorption on Napier grass-derived adsorbent in synthetic

Conclusion

BET surface area of Napier grass-derived adsorbent was 182.53 m^2/g and average pore diameter was 2.9579 nm. Napier grass-derived adsorbent in synthesis water and tap water had point of zero charge (PZC) was 7. Napier grass-derived adsorbent at the optimal dosage (2.0 g/L) had a high removal efficiency of DCAN both in synthetic water and tap water (96.3% and 95.4%, respectively). The presence of organic and inorganic matter in tap water seems to affect the DCAN removal efficiency. Kinetic adsorption of Napier grass-derived adsorbent in synthetic water and tap water were fit to the pseudo-second order. In addition, the adsorption isotherm results indicated that the adsorption mechanism of DCAN on Napier grass-derived adsorbent was physical adsorption. With the highest DCAN removal percentage by using Napier grass-derived adsorbent, it indicated that Napier grass-derived adsorbent is high potential to use as low-cost adsorbent for remove DBPs from water. However, the column experiment condition also needs to be clarified before utilized in the real situation.

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Analysis and Needs Assessment of Chemical Response and Hazardous Substances of Bangkok Fire Fighters

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Abstract

This study aimed to analyze and assess of chemical response and hazardous substances of Bangkok Firefighters (Fire and Rescue Department) and use the Analytic Hierarchy Process (AHP) to prioritize management issues. The study is a mixed method with 400 officers for the sample group and using the identification of informants through purposive sampling and willingness to provide information after collecting the data, the statistics used for testing were: descriptive statistics, percentage statistics, mean, and adjusted PNI index values. The sample group had a bachelor's degree (46.75%), had experience working as a fire officer in Bangkok for more than 9 years (54.50%), and had training experience in chemicals and hazardous substances in 1-3 training courses (53.25%). The results of AHP analysis found 5 management issues. For management to be used effectively, it can be grouped holistically and arranged in descending order. The stakeholders give the most importance to reviewing the plan to extract lessons and find limitations or obstacles in carrying out activities to propose policies for the next time (0.44), the measures to prevent dangers from emergencies, chemicals, and hazardous substances (0.26), the creating a plan to prevent and respond to emergencies from chemicals and hazardous substances at fire and rescue stations (0.14), the preparing emergency response teams from chemicals and hazardous substances at fire and rescue stations (0.10), and the preparing equipment for emergency response from chemicals and hazardous substances at fire and rescue stations (0.06), respectively. The application of the analysis results in managing problems that require the most attention is reviewing plans to draw lessons and find limitations or obstacles in carrying out activities to propose policies for improvement, change, and development of operating models to be consistent with most current situations. Moreover, it is a guideline for developing measures to prevent emergency chemical hazards and hazardous substances while working that will help reduce the loss of property and life.

Keywords : Firefighters; Need assessment; Chemicals and hazardous substances

Introduction

The current disaster situation in Thailand and Bangkok has many disasters occurring and becoming more severe due to various factors and changing trends as a result of global warming and climate change. There were also social changes in various aspects, such as change from rural society to urban society, the increase in workers from neighboring countries when the ASEAN community opened. Changes from various climatic and social factors affect using science and technology in various developments including chemicals and hazardous substances that are used in various activities in the agricultural sector, industrial sector, and many other activities [1]. The results of using various chemicals and hazardous substances without knowledge and understanding as well as a lack of caution regarding safety in production, storage, packaging, and transportation. Regulatory developments often arise from significant process safety incidents. The scope of regulation and the quality of enforcement vary from country to country, generally influenced by regulations from developed countries [2], but at present the regulations have not been enforced to the same level, which may cause accidents and damage to life and property. It can also affect health and the environment. Therefore, it is necessary to have preventive measures and be prepared to solve the problem of chemical and hazardous substance accidents in the event of an emergency, this often causes the rapid spread of toxins but can be measured using modern technology [3] such as detection technology modern communication technology and database. This allows us to use simulation experiments to analyze serious accidents caused by hazardous chemicals. Due to the toxicity and spread of hazardous chemicals, these accidents often result in not only serious economic losses but also traffic congestion at the same time [4]. This includes the risk-based response characteristics and response to security events of the event. Progress assessment Information about the properties of hazardous chemicals protective measures Various precautions are taken at all levels of government and private sector operations [5]. Risk analysis is very important for preventing and mitigating potential accidents. Practical risk assessments can use models and data from networks that can identify other risk factors that may occur and result in operational failure. In emergencies, we can reduce the accident rate during work by using the Fuzzy Logic method, which can reveal defects in some work equipment even if strict measures are followed [6]. Bangkok's population has greatly increased in the past. There is continuous expansion of urban areas. It is the center of progress in every aspect. There is a high density of buildings and various types of housing [7]. If security management is not efficient enough when a public disaster occurs and cannot be solved in time for the situation. Often causing damage and loss at a severe level. It affects the economy both in the short term and in the long term [8], and may cause great damage to society, especially the psychological which is difficult to heal in a short period. Lack of confidence in the safety of people's lives may affect their long-term health [9]. Chemical hazards are specific hazards. It requires the use of specialized expertise of officials from various agencies. In the Bangkok area, these include the Health Department, the Department of Disaster Prevention and Mitigation, the Pollution Control Department, and the Department of Disaster Prevention and Mitigation. In response to chemicals and hazardous substances, it is necessary to take preparedness measures for officials from the agency able to support chemical and hazardous material accident operations on time by preparing emergency action plans with clear guidelines strengthening the capacity of command personnel according to the command system at the scene of the incident and emergency operators in chemical disaster suppression techniques. Including preparing appropriate tools and equipment to effectively manage chemical hazard emergencies and safe for officials people in the area and reduce the impact on the quality of the surrounding environment [10].

This study has the objective to analyze of chemicals response and hazardous substances of Bangkok Firefighters (Fire and Rescue Department) in the actual conditions in to assess and prioritize emergency response needs to chemicals and hazardous substances of Firefighters. The results of the study will be an important database for considering and applying information to develop clear emergency action plans that can be used effectively.

Material and Methods

This study is a mixed methods and all details of the study procedures were qualitative part and Quantitative part are shown in Fig. 1 and below.

1. Qualitative research, collect information from various documents that are theories and concepts, related research documents, and government documents regarding policy implementation for analysis the needs in response to chemicals and hazardous substances of Bangkok fire officials.

Collect data using an interview form as a tool for collecting data and analyze management issues holistically using the Analytic Hierarchy Process (AHP).

2. Quantitative research, conduct a study on the Office of Disaster Prevention and Mitigation Bangkok (Bangkok Fire and Rescue Department) to collect data. The population used in this research is Firefighters of the Bureau of Disaster Prevention and Mitigation Bangkok Data were collected from a sample group of 10 fire stations per fire station, 40 stations, totaling 400 people, using the identification of informants. The purposive sampling and willingness to provide information after collecting the data was analyzed with the SPSS statistical experiment program. The statistics used for testing were: descriptive statistics, percentage statistics, mean, adjusted PNI index values.

Results and Discussion

The results found that the characteristics of a sample group of 400 firefighters in Bangkok had different basic characteristics. The majority of the sample was male 97.75%, had a bachelor's degree (46.75%), and had experience working as a fire officer in Bangkok for more than 9 years 54.50% (Table 1). Moreover, most of the sample group had 1-3 training courses on chemicals and hazardous substances 53.25% and belonged to the Fire and Rescue Operations Division Fire and Rescue Operations Division 1 for 27.25% (Table 2).

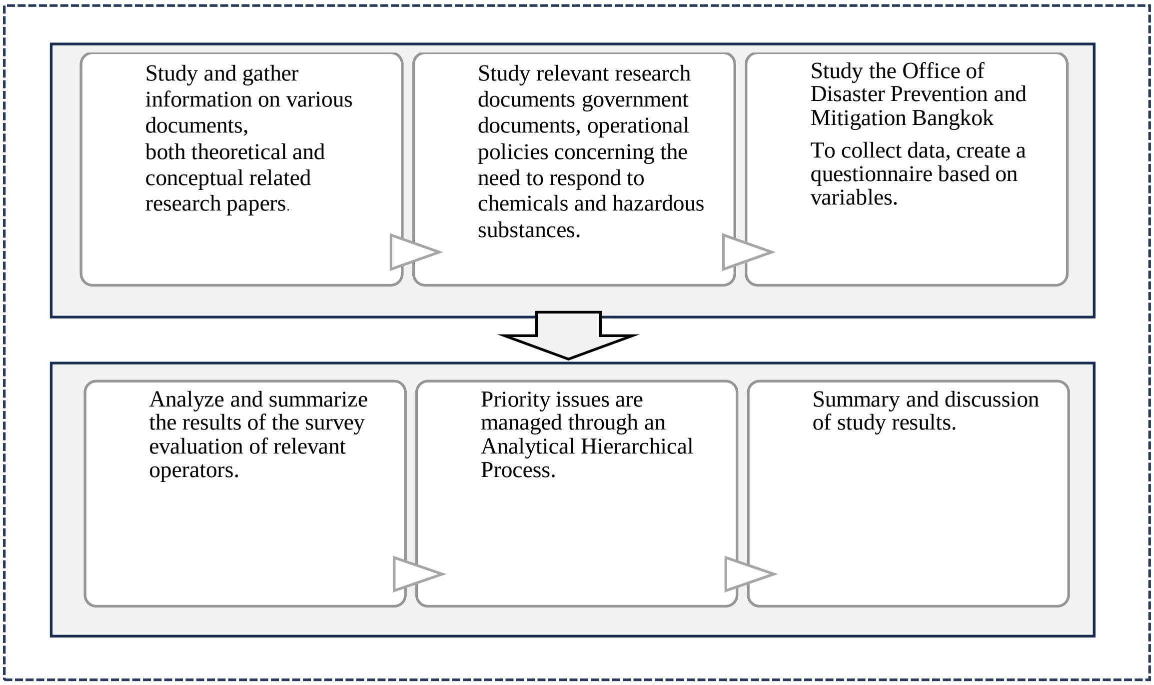

Figure 1 Work processes

Table 1 General information of the sample

Questions	Male		Female		Sum	
	Total (person)	p.c. (%)	Total (person)	p.c. (%)	Total (person)	p.c. (%)
Age						
less than 25 years	7	1.75	1	0.25	8	2.00
25 – 35 years	86	21.50	5	1.25	91	22.75
36 – 45 years	215	53.75	3	0.75	218	54.50
more than 45 years	83	20.75	0	0	83	20.75
Total	391	97.75	9	2.25	400	100
Highest educational qualification						
Professional certificate	40	10.00	2	0.50	42	10.50
Higher vocational certificate	111	27.75	2	0.50	113	28.25
Bachelor's degree	187	46.75	4	1.00	191	47.75
Master's degree	49	12.25	1	0.25	50	12.50
other	4	1.00	0	0	4	1.00
Total	391	97.75	9	2.25	400	100
Work experience current position						
less than 1 year	10	2.50	1	0.25	11	2.75
1-3 year	58	14.50	4	1.00	62	15.50
4-6 year	58	14.50	3	0.75	61	15.25
7-9 year	47	11.75	0	0	47	11.75
more than 9 years	218	54.50	1	0.25	219	54.75
Total	391	97.75	9	2.25	400	100

Table 2 Training experience in chemicals and hazardous substances

Questions	Male		Female		Sum	
	Total (person)	p.c. (%)	Total (person)	p.c. (%)	Total (person)	p.c. (%)
Training experience						
No training experience	148	37.00	8	2.00	156	39.00
Have experience in 1-3 training courses	212	53.00	1	0.25	213	53.25
Experienced in more than 3 training courses	31	7.75	0	0	31	7.75
Total	391	97.75	9	2.25	400	100
Under the Fire and Rescue Operations Division						
Fire and Rescue Operations Division 1	108	27.00	1	0.25	109	27.25
Fire and Rescue Operations Division 2	82	20.50	5	1.25	87	21.75
Fire and Rescue Operations Division 3	48	12.00	0	0	48	12.00
Fire and Rescue Operations Division 4	29	7.25	0	0	29	7.25
Fire and Rescue Operations Division 5	101	25.25	2	0.50	103	25.75
Fire and Rescue Operations Division 6	23	5.75	1	0.25	24	6.00
Total	391	97.75	9	2.25	400	100

The results of this research are consistent with the chemical accident management cycle of the Pollution Control Department which has established a cycle of practice, there were protective measures, a planning aspect, a preparation aspect, and an emergency response. Content analysis results were obtained from additional suggestions in the questionnaire and inductive analysis (analytic analysis) to create a summary of management issues. There were additional suggestions from experts in the process of analyzing the consistency values of the tools (Item Objective Congruence Index: IOC) by the analysis results IOC = 0.96 IOC (acceptance values range from 0.8 –1) found that this is the issue of reviewing the plan to extract lessons and find limitations or obstacles in carrying out activities. Suggestions from stakeholders who are separate from the research issues can be analyzed to prioritize overall management issues, which will make the conclusions more complete. Results of analysis of management issues with analytical hierarchical process using a total of 16 people involved as stakeholders and related parties in 5 groups, there were 3 academics from universities with courses in safety management, 3 academics from universities with courses in safety and health management, 5 executives of agencies or organizations that provide programs training, 5 interested in training and 3 executives of the agency or organization responsible for organizing the training (Table 3). The results of AHP analysis found that there were a total of 5 management issues. In order for management to be used effectively, it can be grouped holistically. Arranged in descending order : 1) Reviewing the plan to extract lessons and find limitations or obstacles in carrying out activities in order to propose policies for the next time. 2) Measures to prevent dangers from emergencies, chemicals and hazardous substances while working. 3) Creating a plan to prevent and respond to emergencies from chemicals and hazardous substances at fire and rescue stations. 4) Preparing emergency response teams from chemicals and hazardous substances at fire and rescue stations and 5) preparing equipment for emergency response from chemicals and hazardous substances at fire and rescue stations, respectively as shown in Table 4.

Applying the results of the analysis of the overall sequence of management issues in the analytical hierarchy process. It shows the issues that need the most attention, including reviewing the plan to extract lessons and finding limitations or obstacles in carrying out activities to propose policies for the next time. It is an important part of improving, changing, and developing the style and methods of operation to be most consistent with the present. Discovering operational limitations Including other factors beyond our control that will affect the overall picture of operations in various emergencies. Second are measures to prevent danger from emergency chemicals and hazardous substances while working. Because having good measures will reduce the loss of property and life. This will be related to restructuring the workforce for efficient workers or reducing the loss of important personnel. It is also an indication of the efficiency and stability of the organization. Other than that, the other points are of similar importance as the details are practically consistent. which can be developed together. Presenting the results of the analysis of management issues can also be used to develop an efficient working system. Having a model and receiving information from stakeholders is essential to operating in almost any emergency situation. Lessons learned can lead to the creation of appropriate policies and will create a learning process for efficient and sustainable development of both the agency and the network in the future.

Table 3 Conditions that should be actual condition and necessary needs in response to chemical emergencies and hazardous substances

List	Should be (I)		Actually (D)		$PNI_{modified}$	Order importance	Order essential requirements
	$\bar{X}$	SD	$\bar{X}$	SD			
1. Measures to prevent emergency hazards from chemicals and hazardous materials while working.							
1.1 Fireman receive training in controlling, managing, or responding to emergencies from chemicals and hazardous substances.	3.87	1.14	2.22	1.06	3.30	3	high
1.2 Risk levels from chemicals and hazardous substances are assessed of establishments in the area of responsibility.	3.84	1.14	2.40	0.93	3.22	4	high
1.3 There is a survey and collection of data on the type and quantity of chemicals stored or used of establishments in the area of responsibility.	3.94	1.14	2.49	1.14	3.30	3	high
1.4 Workers can use safety documents such as chemical labels, MSDS manuals. To correctly respond to chemical and hazardous material accidents.	3.98	1.16	2.34	1.17	3.39	2	high
1.5 Workers wear personal protective equipment and equipment. while working correctly every time.	4.09	1.09	2.76	1.25	3.41	1	high
Total average	3.94	1.13	2.44	1.11	3.32	-	high
2. Preparation of equipment for responding to emergencies from chemicals and hazardous substances of fire and rescue stations.							
2.1 Have chemical protection suit level A or B or C.	4.07	1.12	2.38	1.22	3.48	2	high
2.2 Have personal protective equipment (PPE) such as masks, gloves, and shoes.	4.03	1.09	2.86	1.21	3.32	7	high
2.3 There are materials and tools to respond to accidents caused by chemical spills and hazardous materials spills, such as gas measuring tools. Chemical absorbent materials, sand, shovels, chemical containers, etc.	4.12	1.10	2.89	1.30	3.42	3	high
2.4 There are safety area control equipment such as distance barrier tape, rubber cones, danger warning signs, etc.	4.02	1.10	2.56	1.23	3.39	5	high
2.5 Have a personal communication device.	4.09	1.12	2.93	1.36	3.37	6	high

List	Should be (I)		Actually (D)		$PNI_{modified}$	Order importance	Order essential requirements
	$\overline{X}$	SD	$\overline{X}$	SD			
2.6 There is first aid equipment.	4.10	1.17	2.17	1.17	3.57	1	high
2.7 There is a sound amplifying device. To be used to provide warnings to officials and people in the vicinity.	3.93	1.16	2.45	1.18	3.57	1	high
2.8 There are substance measuring tools such as air detectors. Temperature measuring device, etc.	3.98	1.17	2.30	1.07	3.40	4	high
Total average	4.04	1.13	2.57	1.22	3.41	-	high
3. Preparing emergency response teams for chemicals and hazardous substances of fire and rescue stations.							
3.1 The fire station's emergency operations unit has been prepared.	3.91	1.16	2.27	1.06	3.32	3	high
3.2 Plans are rehearsed, plans are reviewed, and plans are revised for use in suppressing emergencies from chemicals and hazardous substances.	3.92	1.15	2.25	1.07	3.32	3	high
3.3 Define roles and responsibilities in responding to chemical and hazardous substance emergencies according to the specified plan.	3.95	1.14	2.22	1.01	3.38	2	high
3.4 Equipment is inspected and maintained. Used in responding to chemical and hazardous substance accidents.	3.97	1.16	2.37	1.08	3.32	3	high
3.5 There is coordination for joint operations between relevant departments both internally and externally.	4.02	1.14	2.41	1.11	3.42	1	high
Total average	3.95	1.15	2.30	1.06	3.37	-	high
4. Preparation of emergency prevention and response plans from chemicals and hazardous materials of fire and rescue stations.							
4.1 There is coordination of control. and manage the area to evacuate and help the injured.	4.01	1.17	2.39	1.11	3.41	2	high
4.2 There is an action plan to respond to chemical and hazardous substance accidents.	3.99	1.19	2.36	1.16	3.40	3	high
4.3 There is an action plan for cleaning up chemical contamination for workers and disaster victims.	4.02	1.16	2.33	1.10	3.44	1	high
4.4 There is coordination to jointly operate between the relevant internal and external agencies.	4.04	1.14	3.18	1.29	3.25	5	high
Total average	4.02	1.15	2.68	1.19	3.36	-	high

Note : "I" = the condition that should be in response to a chemical emergency and hazardous substances.
"D"= the actual condition for responding to a chemical emergency and hazardous substances.

Table 4 Analysis of management issues with Analytic Hierarchy Process (AHP)

STAKEHOLDERS	**MANAGEMENT ISSUES SCORE**				
	Reviewing the plan to extract lessons and find limitations or obstacles in carrying out activities in order to propose policies for the next time.	**Measures to prevent dangers from emergencies, chemicals and hazardous substances while working.**	**Creating a plan to prevent and respond to emergencies from chemicals and hazardous substances at fire and rescue stations.**	**Preparing emergency response teams from chemicals and hazardous substances at fire and rescue stations.**	**Preparing equipment for emergency response from chemicals and hazardous substances at fire and rescue stations.**
1	0.45	0.26	0.14	0.09	0.06
2	0.53	0.30	0.06	0.05	0.06
3	0.46	0.26	0.11	0.11	0.06
4	0.56	0.14	0.15	0.08	0.07
5	0.39	0.22	0.20	0.12	0.07
6	0.30	0.22	0.17	0.23	0.08
7	0.32	0.35	0.13	0.14	0.06
8	0.36	0.37	0.13	0.09	0.05
9	0.23	0.30	0.16	0.17	0.14
10	0.49	0.27	0.13	0.06	0.05
11	0.45	0.26	0.12	0.09	0.08
12	0.55	0.20	0.12	0.08	0.05
13	0.50	0.25	0.16	0.05	0.04
14	0.56	0.24	0.10	0.06	0.04
15	0.31	0.15	0.21	0.17	0.16
16	0.57	0.25	0.08	0.06	0.04
average	0.44	0.26	0.14	0.10	0.06
				(C.I.)	**0.10**
				(C.R. <0.1)	**0.09**

Conclusions

This research is an assessment of the chemical response and hazardous substances of Bangkok Firefighters. The objective is to study the conditions that should be and the actual conditions in responding to chemical and hazardous substance emergencies and assess and prioritize the needs of Bangkok firefighters in responding to chemical and hazardous material emergencies. The sample group was male (97.75%), had a bachelor's degree (46.75%), and had experience working as a fire officer in Bangkok for more than 9 years (54.50%). More than half had training experience in chemicals and hazardous substances in 1-3 training courses (53.25%) and belonged to Fire and Rescue Operations Division 1 (27.25%). The results from AHP found the stakeholder's group gave the most importance to the issue of reviewing the plan to extract lessons and find limitations or obstacles in carrying out activities to propose policies for the next time, which is consistent with real conditions in measures to prevent danger from emergency chemicals and hazardous substances. Therefore, it is important to review plans and provide information to present policies that should be given priority to have measures to prevent emergency chemical hazards and hazardous substances in work that are appropriate for actual conditions in the future.

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Monitoring and Surveillance of Algal Bloom Using IoT Technology

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Abstract

Algal blooms have negatively affected people in terms of economy, society, and environment. This research was focus on the using of Internet of Things (IoT) to determine chlorophyll A and sea surface temperature at the Gulf of Thailand. The IoT used in this study was related to the Aqua MODIS (Moderate-Resolution Imaging Spectroradiometer) imagery and SeaDAS (SeaWiFS Data Analysis System) program. This program showed the results of the Satellite data with chlorophyll A and sea surface temperature during Jan 7-13, 2023. The results showed that chlorophyll A concentrations were found in the study area with the range of 2.31-4.35 mg/m^{-3} while the sea surface temperature were determined with the range of 28- 29°C. However, this study was limited by using the only data from the Aqua MODIS satellite. Therefore, it will be better to study the data comparison from satellite photos with field measurements of sea surface temperature and chlorophyll A content in the appropriate locations.

Keywords : Algal bloom; IoT technology; Chlorophyll-A; Sea surface temperature

Introduction

The Internet of Things (IoT) connects people and machines across various domains and applications by integrating data from sensor devices into the Internet [1]. In recent years, the IoT has advanced significantly. It can be applied to many industries and environments. IoT devices can establish connectivity with the Internet, thereby enabling the extraction and utilization of gathered data to augment workplace productivity, facilitate informed decision-making, and even predict variables that may exert influence. Moreover, the potential for real-time data applications is evident. The adoption of IoT technology holds the promise of expeditiously resolving operational challenges. For example, it allows for real-time monitoring of work environments, fostering continuous learning from job experiences, environmental tracking, and similar applications. The future portends the emergence of a multitude of novel IoT technologies, driven by the distinctive traits and advantages they offer, a trend underscored by the extensive global research engagement. The ubiquity of IoT is further exemplified by the deployment of 27 billion IoT devices worldwide in 2018, a figure projected to surge to an astounding 75 billion by 2025 [2].

The Thailand Digital Technology Forecast 2035, published through a collaboration between Frost & Sullivan and the Digital Economy Promotion Agency (depa) [3], has expounded upon the IoT technology landscape in Thailand. This technological facet significantly permeates the public, corporate, and private sectors, yielding substantial implications. The forecast, underpinned by an average annual growth rate, has anticipated the escalation of IoT technology's worth from 3.6 billion Thai Baht in 2018 to a substantial 440 billion by the year 2035.

From the current trend of using the Internet of Things (IoT), IoT technology has been applied to predict the occurrence of algae blooms. This technology has been used for Studying the amount of chlorophyll-A at the sea surface [4, 5]. Considering that the phenomenon of whale excrement (algal bloom) constitutes a natural occurrence, the exploration of IoT technology for the purpose of monitoring and surveilling such events emerges as a strategically advantageous pursuit. The upsurge of marine plankton, encompassing bacteria, protozoa, and phytoplankton, characterizes this phenomenon. The presence of deceased algae or phytoplankton, buoyant at the water's surface, obstructs the photosynthesis process of plants and corals, precipitating a direct impact on marine ecology. This cascade effect entails a reduction in water's oxygen content, culminating in the demise of indigenous flora and fauna.

Empirical investigations into the nation's instances of whale excrement occurrences revealed a discernible spectrum of intensity, spanning locales from Bangsaen Beach to Sriracha, encompassing areas such as Ao Udom and Ang Sila. Notably coinciding with the onset of the rainy season spanning June to August, this phase witnesses consecutive days marked by rain, accompanied by overcast skies and gusty winds. Within the ambit of this inquiry, scholars ascertained an element of uncertainty pertaining to the exact origins and modalities of whale excrement's appearance. However, research established the nexus in Chonburi province on Thailand's eastern coastline. According to this comprehensive study, there is a palpable elevation in the quantity of "phytoplankton" blooms, particularly from the genus "Noctiluca". These phytoplankton organisms eventually perish and undergo degradation due to the abundant availability of nutrients under conducive conditions. Wind and cloud cover further accentuate this process. Consequently, the remnants of these organisms, colloquially referred to as "carcasses", are swept ashore by the tide along the coastline [6]. Algal bloom significant affect to environment and people. In this context, the integration of IoT technology assumes paramount importance in the surveillance and tracking of recurrent instances of whale excrement. This implementation not only facilitates data collection but also enables comprehensive analysis and predictive modeling, thereby engendering the capacity to devise remedies, forestall recurrences, and promptly alert tourists to these events. Hence, this study examines the utilization of IoT technology to access data on chlorophyll A content and sea surface temperature.

Materials and Methods

Materials

The materials used in this study were composed of a computer, Spyder (Python 3.9), SeaDAS Program (SeaWiFS Data Analysis System) version 8.2 (available for download from http://seadas.gsfc.nasa.gov). and data Aqua MODIS (available for download from http://oceancolor.gsfc.nasa.gov/).

Methods

The research target of this study was initiated by determining the specific area of the Gulf of Thailand. Implementation of the study involved coding activities utilizing the Python 3.10 programming language. This phase also included the installation of key libraries, including Beautifulsoup 4, Selenium, Webdriver Manager, and a schedule for encoding satellite images. Pertinent data from NASA's Moderate Resolution Imaging Spectrometer (MODIS), specifically chlorophyll A and sea surface temperature measurements, were selected [7]. These data sources were extracted from Terra/Aqua MODIS sensors, with the TERRA satellite serving as the measurement instrument (available for download from http://oceancolor.gsfc.nasa.gov/). Data extraction targeted information pertaining to chlorophyll A content and sea surface temperature from the MODIS satellite images. Rectification of mathematical discrepancies was facilitated through the utilization of the 'Reproject' option within the SeaDAS (SeaWiFS Data Analysis System) program, thereby ensuring data accuracy. Thorough analysis and interpretation of the accumulated data constituted the final phase of the research process.

Results and Discussion

The IoT technology was used to facilitate the evaluation and prediction of the algal bloom phenomenon. The satellite imagery, chlorophyll A content, and sea surface temperature data were encoded by using the satellite image information. The findings can be categorized into three principal segments: 1) the results from the coded access of satellite image data, which displayed chlorophyll A content and sea surface temperature through temporal adjustments for data recording, 2) the SeaDAS (SeaWiFS Data Analysis System) program that was used for analyzing the data and 3) the analysis of chlorophyll A and sea surface temperature from satellite images in the Gulf of Thailand.

Results from coded access of satellite image data

The coding implementation permitted the accessibility of satellite image data, manifesting chlorophyll A content and sea surface temperature through temporal adjustments. This code facilitated the acquisition of satellite images capturing sea surface temperature and chlorophyll A content, particularly in the geographical coordinates encompassing 13.6 to 12.5 degrees north latitude and 99.92 to 101 degrees east longitude within the Gulf of Thailand (Figure 1). This code schedules the regular or as-needed recording of data to capture the MODIS signal.

After that, the code was divided into two sections: one for retrieving data on chlorophyll content and the other for retrieving data on sea surface temperature. The final step involves creating the code that instructs the other two portions of the code to function as a whole. There is a designated work period.

The time setting for recording information on sea surface temperature and chlorophyll A content was shown in Figure 2. The configuration of Case #1 recorded the data every 9 and 12 minutes immediately, while the data were planned to be recorded once per day at 22.21 or 22.24 p.m. in Case #2 (Figure 2).

The data were saved at pre-defined intervals, and this information was subsequently utilized to generate an NetCDF (Network Common Data Form) for chlorophyll A content calculations. Image recording of chlorophyll A content is and sea surface temperature. Images that were successfully recorded showed chlorophyll content. The image that successfully recorded the level of chlorophyll A and temperature of the sea surface were called L2.OC.NRT, and L2.SST.NRT respectively.

The SeaDAS (SeaWiFS Data Analysis System) program was used for analyzing the data.

When receiving data from the satellite downloaded to the SeaDAS programs, Bands Chlor_a (sea surface temperature) were chosen and then opened as shown in Figure 3.

```
#map

driver.find_element(By.CSS_SELECTOR,"input[name='n']").send_keys("13.6")
driver.find_element(By.CSS_SELECTOR,"input[name='w']").send_keys("99.92")
driver.find_element(By.CSS_SELECTOR,"input[name='e']").send_keys("101")
driver.find_element(By.CSS_SELECTOR,"input[name='s']").send_keys("12.5")
driver.find_element(By.CSS_SELECTOR,"input[value='Find swaths']").click()
```

Figure 1 The coordinates of the Gulf of Thailand area.

```
    print("L2.SST.NRT [illegible]")

#case 1
schedule.every(9).seconds.do(first_file)
schedule.every(20).seconds.do(second_file)


#case 2
#schedule.every().day.at("22:21").do(first_file)
#schedule.every().day.at("22:24").do(second_file)

while True:
    schedule.run_pending()
    time.sleep(1)
```

Figure 2 selecting the time that satellite data is recorded

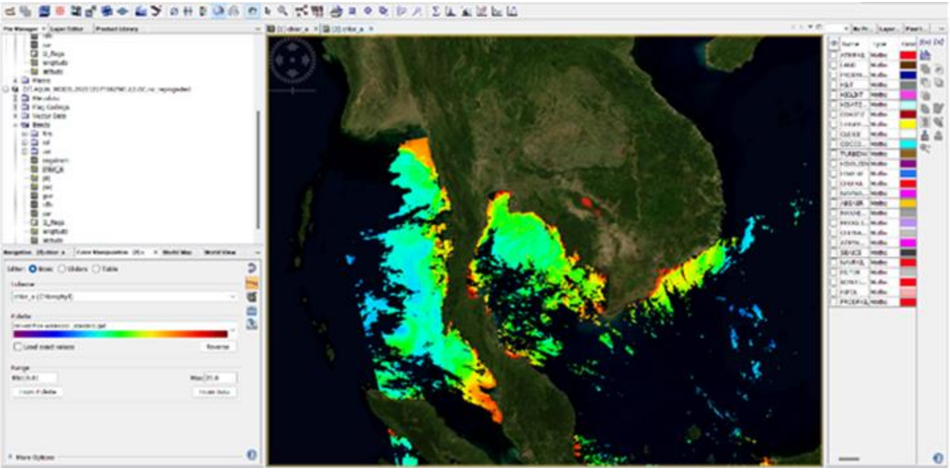

Figure 3 Analyzing satellite data with the SeaDAS (SeaWiFS Data Analysis System) program

For seven days duration (January 7 to January 13, 2566), the software granted access to experimental data. The study employed satellite images to discern chlorophyll A content and sea surface temperature.

As shown in Figure 4, chlorophyll A levels was about 4.35 mg/m^{-3} on January 7 and 2.71 mg/m^3 on January 8. On January 10–12, the highest concentrations of chlorophyll A were 2.31 mg/m^{-3}, 2.40 mg/m^3, and 2.60 mg/m^{-3}, respectively. The pinnacle concentration of chlorophyll A of 3.73 mg/m^{-3} was observed on January 13.

As shown in Figure 5, the SeaDes program was employed for the analysis of sea surface temperature data. The results revealed that the maximum temperatures on January 7 and 8 reached 29 ^oC and 28 ^oC, respectively. On January 9–11, the highest sea surface temperatures were 28 ^oC. The highest sea surface temperatures on January 12 and 13 were 28.91 ^oC and 28.4 ^oC.

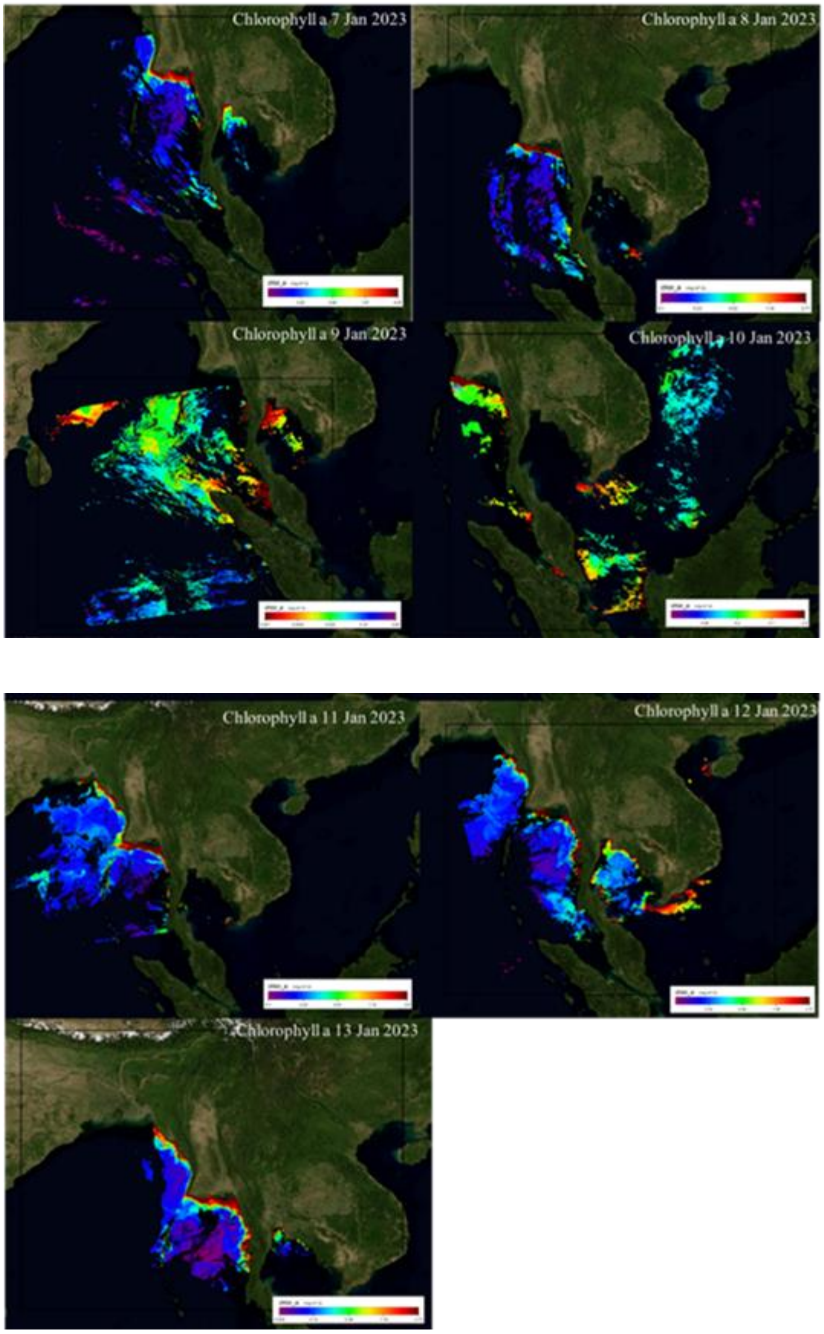

Figure 4 Analysis of satellite images utilizing the SeaDes program - depiction of extracted chlorophyll A content data from the MODIS Receiver (January 7–13, 2023)

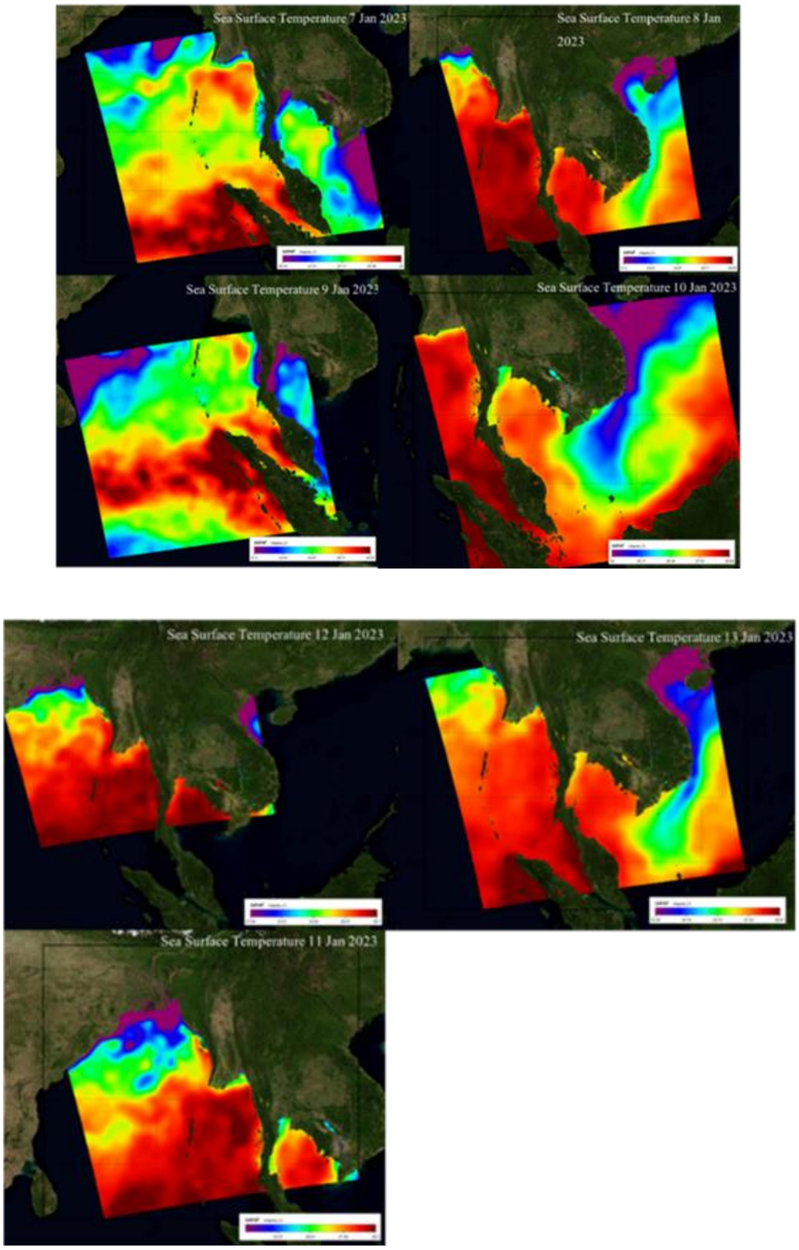

Figure 5 Recorded sea surface temperature data results from the MODIS receiver utilizing the SeaDes Program for satellite image analysis (January 7–13, 2023)

The results of the satellite images that were analyzed by MODIS-Terra and SeaDAS-Aqua programs showed that they could evaluate the level of chlorophyll-A and temperature of the sea surface. However, it has been reported that chlorophyll-a diffusion from MODIS-Terra and MODIS-Aqua monthly satellite data with chlorophyll data collected in the field by research vessels in 2012 showed that most of these field results were consistent with MODIS data [8].

Furthermore, the levels of chlorophyll-A and the sea surface temperature were determined to be compatible with the information from the Geo-Informatics and Space Technology Development Agency (Public Organization) (Figure 6). This study demonstrates the dependability of chlorophyll-A content data and the sea surface temperature measurements collected from satellites.

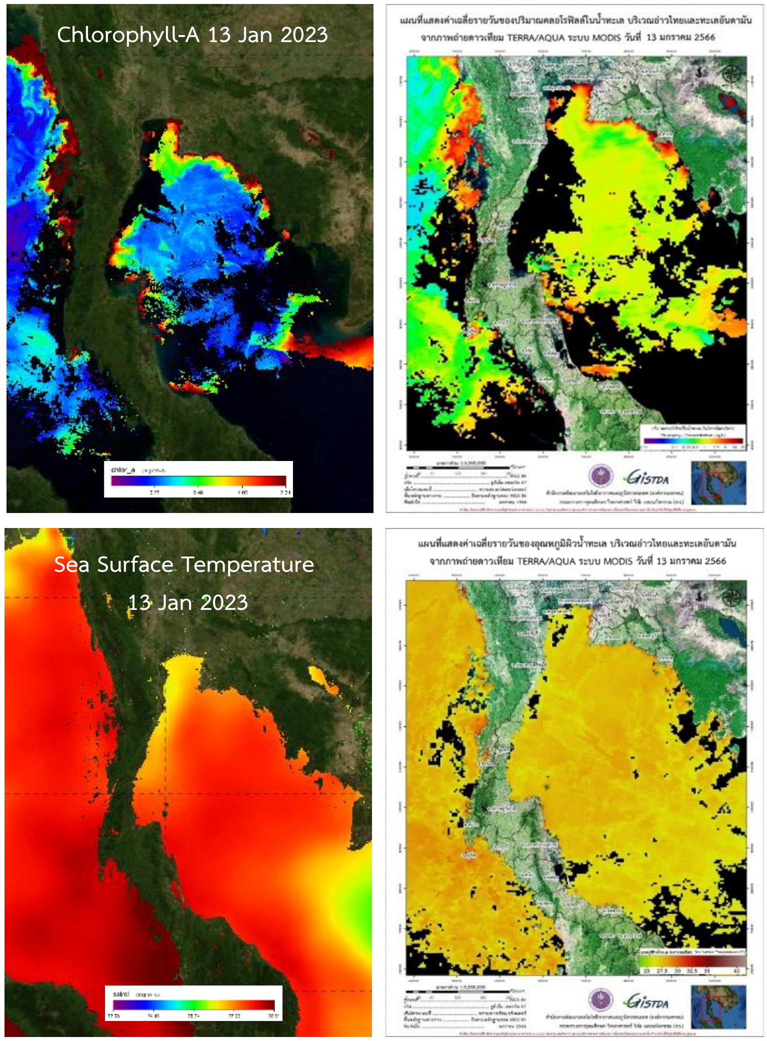

Figure 6 chlorophyll A and sea surface temperatures January 13, 2023 Compare with pictures from Geo-Informatics and Space Technology Development Agency (Public Organization) [9]

Conclusion

The IoT technology was used to improve the access data on sea surface temperature and chlorophyll-A. Considering about using the SeaDes program which displays values from satellites and digital image analysis, the access MODIS satellite data are capable of digital images analysis from satellite data displays the temperature of the sea surface and the concentration of chlorophyll-A from image registration. The data appears as a color bar that showed the amount of chlorophyll and the sea surface temperature. However, the satellite imaging system has a limitation in terms of a passive sensor satellite data system which is unable to image the research region of MODIS. The further research could be the extension of data comparison from satellite photos with measurements of sea surface temperature and chlorophyll content in the appropriate locations.

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